# SCIENCE AND SOCIAL WELFARE IN THE AGE OF NEWTON

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# SCIENCE AND SOCIAL WELFARE IN THE AGE OF NEWTON

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# PREFACE

THE first four chapters of this essay give the substance of four lectures delivered in the University of London in Lent Term, 1936. For permission to reprint the third and fourth, which were published as articles, I have to thank the editor of the *Economic Journal* and the Royal Economic Society, the editor of the *Economic History Review* and the Economic History Society. For the like permission for the Appendix I have to thank the editor of the *English Historical Review* and Messrs. Longmans, Green & Co.

I was fortunate in having among my hearers at the London School of Economics several distinguished authorities on the subjects touched in the lectures. They made a number of valuable comments for which I wish to express my gratitude. Finally, I must record my sincere thanks to the University of London for honouring me with its invitation to deliver the lectures.

G. N. C.

OXFORD,
15 *May* 1937.

In the present reprint some small corrections have been made and some further references added at the ends of the chapters.

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# INTRODUCTION

MANY questions have been asked in recent years, and more will be asked in the future, about the place of science in our civilization. The most urgent are those which arise from the application of science to industry and transport: the questions whether we can secure the benefits of improved technology without the economic evils which they sometimes bring; and whether scientists themselves have the power to cure all the social evils which seem to arise from the misuse of science. Although they are urgent, these questions are not new; and history has much to contribute to the answers. This essay is intended to show how these matters stood and what was thought about them, especially in England, in one of the periods in which western civilization was most rapidly moving towards its present state. The period is that from about the time of King Charles II to about the time of Queen Anne.

This may be called the age of Newton, for Newton was the greatest figure in the last and most brilliant phase of the great scientific movement which began long before his time and reached its highest activity in the late seventeenth century. The scientific movement coincided in time with great changes in other spheres: it was in this age that the western countries, England, France, and Holland, took the lead in European industry and commerce, and also in spreading European influence over the world. They were

able to do so partly because they prepared the way for our own age by anticipating something of its character in one special point, namely in the co-operation of science and economic life.

We all know that in our own days this co-operation is one of the driving-shafts of the world. Without it we could have neither the vast industrial production, nor the vast concentrations of economic and political power that make so much of what is best and so much of what is worst in our lives. But science and business are not merely very highly developed, and very closely connected: they are developed and connected by organized social effort. To further them and to draw them together is the work of certain institutions, the whole work of some, part of the work of others. There are research institutions, some of them created by the state, some by industry, some by private wealth. Some are professedly technological, some devoted to 'pure science'. Some are engaged not only in research but also in teaching, and technical education is an integral part of all modern educational systems. Even the elementary and secondary education of boys and girls is moulded by the requirements of a 'machine age'. Thought on many subjects, and not least on social subjects, is influenced by the engineer and the chemist. Applied science has thus influenced the whole structure of society; and we must consider in this earlier period not only the state of knowledge and the practical applications of science, but also the connecting-links supplied by educational

institutions and by social control. We shall find that science, on the one hand, was not a mere product of social development, while, on the other hand, it could not by itself afford sufficient guidance for the movement of society. Between these two limits we shall look, not for a formula or definition, but for a concrete picture of its work.

# I

## SCIENCE AND TECHNOLOGY

To understand the place of science in the civilization of Newton's time, we ought first to show what it was that science, or scientists, contributed to the life about them, and in order to do this it is best to begin from the centre, that is from the history of technology. The most familiar part of that history is the history of inventions, if only because generations of English schoolboys received as prizes the lucid and vigorous lives of the great inventors written by Samuel Smiles. Enthusiasms must have their heroes, and Samuel Smiles provided them for the confident industrialism of the Victorian age; but it is interesting to notice that his view, which has been called the heroic theory of invention, was also held by some of the prophets of applied science in the seventeenth century. It has never been more decidedly expressed than by 'fat Tom Sprat', the first historian of the Royal Society: 'Invention is an heroic thing, and placed above the reach of a low and vulgar genius.'[1] If we were to accept this theory, we might find it difficult to trace systematically the place of the inventive process in social development; we might have to conclude that it resulted from unaccountable flashes of inspiration. There are, however, solid grounds for rejecting the theory. It has indeed been

[1] *History of the Royal Society* (1667), p. 392.

rejected by the most opposite schools of thought. Those who insist on the organic connexion of all the phenomena of social life and who subordinate the individual to social forces, regard the inventor and his ideas as products of the conditions of the time and place where he lives. At the other extreme, the individualist Victorian manufacturers themselves never tired of insisting, before government inquiries into the patent laws, that there was no such thing as pure invention, all was mere adaptation, and if an invention was not made by one man it was sure to be made by another, most of them in fact being hit upon simultaneously by different people coping independently with the same practical difficulties.[1]

These manufacturers had an interest in proving their point: they wanted parliament to imitate the Dutch and the Danes by abolishing the patent law and so relieve them of the duty of paying royalties to inventors. The historian, however, though he has no such practical motive, must in the main agree with them in regarding invention as a process that is carried only in the rarest and simplest instances within the confines of a single mind. Nearly always it results from the conscious or unintentional co-operation of many minds working when the time is ripe for some new device. This view indeed is not new. Some of the facts which lead immediately to it were noticed

[1] See the minutes of evidence before the Royal Commission of 1862–4 (1864, xxix. 321) and the Select Committee of 1871–2 (1871, x. 603; 1872, xi. 395).

long before the time of Sprat. More than a century and a half before that time, in the Renaissance days, when the study of technology was already quickening, Polydore Vergil pointed out that there were many inventions both old and new of which the authors were unknown.[1] This was not because of the darkness of the knowledge of former times, the poor communications and scanty records of the age before printing, an invention which is itself one of the classical examples of the difficulty of naming the true inventor. The same difficulty has recurred ever since, for the inherent reason that almost every invention is —as Francis Bacon repeatedly said of his own great contribution to scientific method—*partus temporis potius quam ingenii*.[2]

In considering the history of technology, then, we need pay little heed to the legends which ascribe its improvements to individuals working independently of their social environment, and less to those which explain them as due to mere 'happy thoughts'. These tales are not confined to the history of technology: there is the story of Newton and the apple. In instances like this, when we know how the great intellectual constructions in question were actually made, no serious student now believes them. No more do we believe the story of James Watt and the boiling

[1] *De Inventoribus Rerum*, III. xviii. I have used the Paris edition of 1505. An abridgement in English was published in 1546.

[2] *Novum Organum*, ed. Fowler, 2nd ed. (1889), pp. 159, 272–3, 328.

kettle. Many people, however, are too credulous of these stories when they are applied to minor inventions about which little is known. Several of them are constantly repeated about inventions of the early capitalist period. William Lee, the reputed inventor of the stocking frame, the most complicated machine used in England in the sixteenth century, is said to have contrived it for some reason connected with a young woman. The simple version of the story is that he was paying his addresses to her, but she seemed to be always more mindful of her knitting than of his presence. A more sophisticated version, in which the hand of the economic historian may be traced, is that she slighted her lover, and that in revenge he invented this machine in order to throw her out of employment. For no version of this ridiculous story is there any real evidence whatever.[1] Cornelius Drebbel, a true scientist, is said, with a similar lack of evidence, to have owed his invention of cochineal scarlet dye to the accidental upsetting of a vessel: the historian of the Royal Society, on the other hand, cited this 'Bow dye' as his only instance of an important industrial invention arising from scientific work.[2]

[1] For the various versions from secondary authorities see W. Felkin, *History of Machine-wrought Hosiery and Lace Manufactures* (1867), pp. 23 ff.

[2] Sprat, p. 391. For Drebbel's invention, which was introduced into England in 1643 by a Dutchman, Kepler, and used at Bow, see F. M. Jaeger, *Cornelis Drebbel en zijne tijdgenooten* (1922); and see below, p. 44, n. 1. Sir Hugh Plat, in his *New and*

Even if we are cautious enough to allow for the possibility of many exceptions, it remains the rule that accidental inventions are of no importance in the great social processes by which our technology has grown. Among these, that which first deserves attention is the conscious effort of scientists to bring inventions about. From the time of the Italian Renaissance there were writers who acclaimed the greatness of the new discoveries and inventions. Polydore Vergil was one: almost daily, he wrote, human industry was finding out some admirable thing, and now there were many such which former ages had lacked.[1] Down to the end of the seventeenth century, indeed, the moderns judged their own achievements by comparison with the ancients, and there was a controversy between those who thought the ancients had been outdone and those who would not admit it.[2] The optimism of the Renaissance, however, was on the side of the moderns, and Francis Bacon, when he exhorted scientists to undertake the conquest of nature, gave this optimism its fullest expression. One

*Admirable Arte of Setting Corne* (1600), c. i, did not, as is sometimes said, ascribe the idea of dibbling wheat instead of sowing it broadcast to the accident that a silly wench deposited some seeds of wheat in holes intended for radishes or carrots. He merely offered this as one of three alternative guesses about the origin of the practice.

[1] II. v.

[2] The work of Pancirollus, *Rerum Memorabilium Libri Duo*, which brings technological inventions amongst others into the argument, though written in the sixteenth century, was translated into English as *The History of Many Memorable Things now Lost*, 2 vols., as late as 1715.

of the last English scientists who expressed himself uncertainly on the relative merits of the two ages was Dr. John Wilkins, the warden of Wadham, who afterwards married Oliver Cromwell's sister. In 1648, the year before the execution of Charles I, he published his *Mathematical Magic*, a very good popular treatise on mechanics and machines. It was a learned book, but it was not the work of a man who looked only backwards. It has speculations about submarines, and flying, and perpetual motion. Yet in this book Wilkins still has to account for the superiority of the works of the Romans and their predecessors: 'Mechanical discoveries', he says, 'are altogether as perfect, and (I think) much more exact than they were heretofore but . . . we have not either the same motives to attempt such works, or the same means to effect them as the ancients had.' He goes on to explain this from their religion, their politics, their ambition, their leisure, their slave-labour.[1]

Already, however, the successes of natural science were so obvious on all hands that science had become a fashion. Among the noblemen and gentlemen who were conspicuous as scientific dilettanti at this time, it is easy to see that the excitement of study was mixed with the hope of gain. Wilkins encouraged them with the hope that in his 'mathematical or philosophical enquiries' . . . 'besides the great delight and pleasure . . . there is also much real benefit to be learned; particularly for such gentleman as employ

[1] *Mathematical and Philosophical Works*, ii (1802), 127–8.

their estates in those chargeable adventures of draining mines, coalpits, etc. . . . and also for such common artificers as are well skilled in the practice of these arts.' This double motive operated in practice. Edward Somerset, lord Herbert, afterwards second marquis of Worcester, is famous for his *Century of Inventions*.[1] For many years he conducted experiments, with the assistance of a German, Caspar Kaltoff,[2] and he set up some new type of pump at Raglan Castle. In 1655, when Raglan had fallen in the Civil War and he was a prisoner in the Tower, he put together this jumbled list of a hundred inventions, new and old, trivial and useful, genuine and imaginary, hoping to commend himself by it to the Protectorate government. After the Restoration he published it with a dedication to Charles II and both houses of parliament, vainly hoping that he might restore his ruined fortunes if his 'stupendious water-

[1] First ed., 1663, reprinted with slight variations at least eight times in the eighteenth and nineteenth centuries. One of the reprints is in H. Dircks, *Life, Times, and Scientific Labours of Edward Somerset* (1865), which takes an extremely favourable view of Worcester's claims. An impartial reader with any knowledge of previous investigations, such as those of Wilkins, in the same fields cannot, in my opinion, accept this view in general; and the idea that Worcester invented a steam-engine can be derived only from arbitrary interpretations of nos. 68 and 98–100 in the *Century*. These conclusions are confirmed by the touching letter of Fr. Walter Travers written to the widowed marchioness in 1670 and printed in C. F. Partington's ed. of the *Century* (1825), pp. lviii ff., especially p. lx.

[2] For Kaltoff's work as a gun-founder see C. ffoulkes, *The Gun-founders of England* (1937), pp. 52–3, 114.

work' were adopted for the water-supply of London.[1] He was not the only English nobleman who had his scientist and his laboratory. The second duke of Buckingham employed a scientist, and it is probably not a mere coincidence that he was interested in promoting the manufacture of glass in England.[2] King Charles himself learnt something of mathematics after his Restoration from Seth Ward, the bishop of Salisbury,[3] and had a laboratory. Prince Rupert, in the peaceful intervals of his life, conducted experiments, one of which has left a permanent trace in the name of the scientific toy called 'Prince Rupert's drops'.

While, on the one hand, men in high place were beginning to look to science for pleasure and profit, on the other the scientists felt that they needed money and the encouragement of the great. John Wilkins, to quote him once more, cited a writer of the previous century to the effect that the reason why the Germans had been so eminent for mechanical inventions is that there had been public lectures instituted among them, not only in the learned languages, but also in the vulgar tongue, for the capacity of every unlettered

[1] The private Act of Parliament of 1663 which gave Worcester a privilege for this invention for ninety-five years is printed, with An Exact and True Definition which does not explain its principle, and bound with some copies of the *Century*, such as that in the British Museum which has the press-mark 58 k 35. It is followed by commendatory verses by his servant James Rollock 'Scoto-Belgo-Brittanus', who seems to have been another assistant.

[2] Sprat, p. 250; Macpherson, *Annals of Commerce*, ii. 560.

[3] Boyle, *Works* (1744), iii. 231.

ingenious artificer.[1] He asked support for science as well as for technical education. 'In these practical studies, unless a man be able to go to the trial of things, he will perform but little.' '*Res angusta domi* and *curta supellex* is that which hinders the promoting of learning in sundry particulars, and robs the world of many excellent inventions.' After telling the story of how Alexander the Great paid for the collection of materials for Aristotle's scientific studies, he succinctly remarked: 'The reason why the world hath not many Aristotles is because it hath so few Alexanders.'[2]

Some of Wilkins's hopes were fulfilled when, in 1662, he and other scientists who had worked together on and off in Oxford and London for a good many years were incorporated as the Royal Society. King Charles II was not an Alexander, and his Society was for many years in recurrent financial straits, but its foundation grouped for common purposes almost all the prominent people in England who were interested in science in whatever way and for whatever reason, and the royal patronage was in itself a powerful aid. It gave the Society a standing which attracted other benefactors. It made people all over the world

[1] This, in his preface to the Reader, is on the authority of Ramus, *Scholae Mathematicae*, book ii, where this is mentioned as one among other methods by which the useful arts were promoted in Nuremberg. The whole second book of Ramus is on the usefulness of mathematics, and lays much stress on the attention paid to them in Germany. The passage in question occurs at pp. 65–6 of the Basel edition of 1569.

[2] Op. cit., p. 197.

glad to answer inquiries and enter into correspondence. The practical or utilitarian motive was clearly present from the first,[1] both in the narrower form of a desire to improve technology and in the wider form of a desire to promote national prosperity. The Society's first charter stated that it was Charles's purpose 'to promote the welfare of the arts and sciences'.[2]

Writers on the early history of the Society have distinguished two periods of its early activities, the Baconian and the Newtonian. The latter, as we shall see, is not altogether an appropriate name for the period after Newton came into touch with the Society, that is, after its first nine years or so; but the preceding period may rightly be called Baconian. Among the earliest members of the Society there was much respect for Bacon's name, and several of them were inspired by his conception of science in the service of humanity. His bust is represented in the symbolic frontispiece of Sprat's history. One of the most influential of the original members was the Hon. Robert Boyle, who was the most faithful follower of Bacon among great scientists. Boyle set

[1] 'The other humane studies I apply myself to' [in addition to ethics] 'are natural philosophy, the mechanics, and husbandry, according to the principles of our new philosophical college, that values no knowledge, but as it hath a tendency to use.' Boyle to Marcomber, 22 October 1646, in Birch's folio edition of his *Works*, i (1744), 20.

[2] Sprat, p. 134; the emphasis on the arts is much stronger in the draft charter by Sir Christopher Wren in *Parentalia* (1750), pp. 196–7.

himself to carry out what one of his correspondents called 'the Verulamian design',[1] and many of the arguments of his excellent but unhappily prolix works take their start from Bacon. His mind constantly ran on the *Usefulness of Natural Philosophy*, and the Second Part of his treatise which has that title is the most important general discussion written in seventeenth-century England on the relation of science to technology. It contains a broad survey of the methods used in industry and the ways in which science was improving them and might be expected to improve them in the future. Boyle argued with great force for the view 'that the Goods of Mankind may be much Increased by the Naturalist's Insight into Trades'. His own interests were wide: he had a first-hand knowledge of mining, as well as agriculture, and made some practical suggestions about assaying.[2] Several of the most energetic members of the Society were of Boyle's way of thinking, and in its Baconian period, it attempted extensive co-operative work in technology and allied fields. This activity appeared to culminate in 1664 with a resolution that the king should 'be desired to give a rule to the two secretaries of state that all proposals that should be made concerning mechanical inventions be referred to the Council of the Society, to be exam-

[1] John Beale, 13 July 1666, in Boyle, *Works*, v. 478.

[2] See his *Previous Hydrostatical Way of Estimating Ores*, reprinted ibid. v. 25. For his views on the repeal of the Act of Henry IV against multiplying gold, ibid. v. 25, 246. See also p. 81 below.

ined by them, whether they were new, true, and useful'.[1] Nothing came of this; but a few days later the Society organized itself into eight committees, of which the mechanical was the most popular, with 69 members, the georgical (agricultural) had 32, and that for histories (or descriptions) of trades had 35. These committees started out with ambitious programmes; and it is perhaps because they were so busy that the records of the Society as a whole show, after their appointment, not more but less evidence than before of a comprehensive and systematic survey of technology. But it was not long before that attempt became much feebler.

There were indeed, as was inevitable in such a mixed company, differences of opinion about the Society's policy, and one of the lines of cleavage in the earlier years was sometimes over this matter. The royal patron and those about him from time to time directed the attention of the Society to practical needs. The king recommended to Robert Hooke, the Society's brilliant professional experimentalist, who could do almost everything, 'the business of shipping', apparently with the result that Hooke tried to devise a movable keel for war-ships.[2] Sir Joseph Williamson, secretary of state, admonished Hooke to be diligent to study things of use.[3] But even when

[1] Birch, i. 391.

[2] Hooke, *Diary*, 6, 12 October 1675; but see 21 September 1675 for evidence that he was already interesting himself in ship-building and other nautical matters.

[3] Ibid., 31 December 1677.

they came from very distinguished quarters, these suggestions sometimes went further than the Society could be carried. In its early years a great deal of its time was taken up with the experiments, ultimately unsuccessful, of Sir William Petty in making a boat with two parallel keels. As early as 1663 the council resolved that the committee in Ireland which was examining Petty's boat 'should be put in mind by the secretary that the matter of navigation being a state concern was not proper to be managed by the Society'.[1] Seventeen years later Petty was still of the utilitarian wing: he 'wished that the members would principally aim at such experiments or observations as might prove of great and immediate use'.[2] In 1685 Mr. Pepys, then doing his greatest work at the admiralty, was president of the Society, and at his instance its records were searched for what related to navigation; but the Society was slow to undertake this, and expressed its reluctance: 'Navigation had never been the general work of the Society.'[3]

[1] T. Birch. *History of the Royal Society*, i (1756), 249.

[2] Ibid. iv. 7. Halley seems to have been on Petty's side: see William Molyneux's letter to him, 8 April 1686, ibid. iv. 475.

[3] Ibid. iv. 396, 462, 464. On Pepys's recommendation Plot investigated the felling of timber, *Phil. Trans.*, xvi. It is perhaps just worth while to mention the complaint of the economic tract *Britannia Languens* (1680), p. 357, in the reprint in J. R. McCulloch, *Select Collection of Early English Tracts on Commerce* (1836): '. . . we prize ourselves in fruitless Curiosities; we turn our Lice and Fleas into Bulls and Pigs by our *Magnifying-glasses*; we are searching for the World in the Moon with our *Telescopes*; we send to weigh the Air on the top of Teneriffe; we invent *Pacing Saddles* and Gimcracks

There seem to have been special reasons which checked the technological and other work of the Society after 1664. The Dutch war began, and it absorbed the energies of some of those fellows who had been most enthusiastic for the work. John Evelyn, for instance, became a commissioner for the sick and wounded and prisoners. Next came the fire of London, which provided years of work for Wren and Hooke. These public calamities interrupted the effort. By 1680 the Society was at a low ebb.[1] In the following years there was something of a revival; but the Society's work on industrial science never regained the level of the first years. By the early eighteenth century technological papers took only a modest place in the proceedings. The *Philosophical Transactions* became a miscellany in which specialized science, especially medical, musical, and botanical, was mixed with antiquities, accounts of travel, and the like. In some volumes of the reign of George I there is nothing at all to interest the economic historian: as the pace of technological change began to quicken, the Royal Society's attention turned elsewhere and indeed became enfeebled altogether. One is tempted to throw the blame on the wars of Louis XIV.

It will be useful here to glance at the parallel course

of all sorts; which are voted Ingenuities, whilst the Notions of Trade are turned into Ridicule, or much out of fashion.'

[1] Evelyn to Pepys, 25 June 1680, in *Hist. MSS. Comm.*, *Eliot Hodgkin Papers*, p. 177; see also Evelyn, *Diary*, 24 January, 5 April 1682.

of events in France. In the more important points there is an astonishing coincidence. Louis XIV imitated his cousin Charles by establishing the *Académie des Sciences* a few years after the foundation of the Royal Society; and its objects were the same—*naturae investigandae et perficiendis artibus*.[1] Its work on technology was less vigorous, but in some ways more systematic than that done in England. One of its members, Perrault, published a series of engravings with full descriptions of machines and inventions approved by the Academy.[2] In 1666 came the setting-up of a committee to examine the methods of artisans and to study the defects of their instruments, which looks like an imitation of the English committee of two years before. A collection of tools was started. But in France, as in England, this attempt soon languished. In 1675, at the instance of Louis XIV, a

[1] For the foundation see P. Boissonade, *Colbert* (1932). The most important authority for the early years is the *Histoire de l'Académie Royale des Sciences*, 11 vols., 1666–99; the most convenient guides Godin, *Table alphabétique des matières contenues dans l'histoire et les mémoires de l'Académie des Sciences*, 1666–1730, 4 vols., 1734, an index by subjects and authors, the volumes being divided chronologically, and Rozier, *Nouvelle table des articles . . . de l'Académie des Sciences*, 1666–1770, 4 vols., 1775–6, which is a subject-index to all the Academy's publications, including the 'Collection académique' from foreign academies. It also has lists of members, officers, &c.; but it does not entirely incorporate everything that is in Godin. There is an author-index in vol. iv.

[2] These are most easily accessible in the reprint *Machines et inventions approuvées par l'Académie des Sciences*, ed. Gallon, of which the first volume was published in 1735. About fifty inventions were dealt with before the close of the seventeenth century.

fresh start was made in studying mechanical questions applicable to manufactures; but again in the sixteen-eighties the minister Louvois used his influence to make the Academy more practical. One scientist had to write a commentary on the work of Frontinus on aqueducts, because aqueducts were being constructed for Versailles. Another had to study fountains. Even work on the problem of longitude was suspended, and on the general map of France which had been started some years before. War-work interrupted the more abstruse scientific studies more directly than in England; several of the best mathematicians were set to work on ballistics. Royal control in the period of the great wars of Louis XIV was exerted in favour of quick practical results.[1] To complete the parallel with England, which in this point extends also to Germany, we may add that after a period of torpor in the eighteenth century, the academic study of technology was resumed with vigour about the year 1760.[2]

Such were the attempts of the English and French governments and scientific societies to improve technology by bringing science to bear on it. What did these attempts achieve? How far did they fulfil the

[1] L. F. Alfred Maury, *L'Ancienne Académie des Sciences* (1864), p. 39.

[2] In 1761 the Académie des Sciences began, on the initiative of Réaumur, the publication of its admirable series of illustrated *Descriptions des arts et métiers*; in Germany Johann Samuel Halle and Peter Nathaniel Sprengel published important technological works about the same time. In England the Society for the Encouragement of Arts, Manufactures, and Commerce was founded in 1754 and held its first exhibition in 1761.

hopes of improving the processes of manufacture and transport? A number of inventions were made by the great scientists. It is not necessary to enumerate them. Every text-book has something to say about the improvements in clocks and watches made by the great writers on mechanics, Huygens and Hooke, if only to claim the credit for one at the expense of the other. Boyle, indeed, rightly claimed that the flourishing new trades of the clock-makers and makers of optical instruments owed their existence to the scientists.[1] These craftsmen worked inventions for which a developed scientific knowledge was necessary. An illustration will best show what this means. In the late seventeenth century much work was done on the theoretical study of friction. Philippe de la Hire wrote a treatise on the type of curves known as epicycloids, the path traced by a point on the circumference of a circle rolling round another circle. At the end of his theoretical treatment he proposed a practical application, namely that cog-wheels made with their teeth cut in epicycloid curves will have the least possible friction.[2]

This is an example on a small scale; there is another, very famous, on the greatest scale, that of the invention of the steam-engine. The gradual development

[1] *Works*, iii. 139.

[2] *Mémoires de l'Académie des Sciences*, ix. 341 ff. According to J. H. M. Poppe, *Geschichte der Technologie*, i (1807), 155, ii. 118–19, the discovery was anticipated by the Dane Römer. Another instance of the application of a knowledge of curves is Coswall's use of parabolas and elliptic lines for curving the staves of casks.

of the principles of this machine, by almost regularly alternate steps of experimental research and practical application, is the classical example of science in alliance with practice. In its later stages it was helped forward by the Royal Society. Not only did Boyle and Hooke, who had begun them earlier, carry on their atmospheric experiments in the Society's meetings, and publish their results under its authority; Savery, the practical man who carried the matter up to its penultimate stage, showed the Society a model of his 'fire-engine', which worked successfully, and a description of it, with a plate, was published in the *Philosophical Transactions*.[1] The final stage in perfecting the engine remained to be taken by Newcomen, and Newcomen was, so far as we know, without scientific education; but there is some reason for believing that he was in touch with Hooke as well as Savery, and none for supposing that his invention was in any sense independent of the long scientific preparation which logically led up to it.[2] This cardinal example shows, then, that the activity of the societies led to practical results of the highest importance; indeed, it shows the same for the whole scientific movement from the time of Galileo, for Boyle, Hooke, Huygens, and Papin were only continuing work which had gone on, stage by stage, from his time to theirs.

This discovery, the most pregnant of all for the

[1] Vol. xxi for 1699, p. 228: the date of the demonstration was 14 June 1699.

[2] See *Dictionary of National Biography*, s.n. 'Newcomen, Thomas'.

future, thus resulted from the co-operation of science and industry. That co-operation, however, had not yet assumed its modern forms. It was, as we all know, looser, but it was not simply looser all along the line. At certain points science began to influence technology long before it touched it elsewhere; at these points again the state began earlier to assist the union, and at these the combinations of science, business, and policy assumed something like their modern forms although, in the greater part of their activities, they were each still comparatively simple, self-contained, and indifferent to one another. What we have to trace is not a process which, at each stage, affects equally all the departments of economic life, all the branches of scientific thought, and all the aspects of social policy. We have to observe how certain branches of science influenced technology long before others could; how certain crafts become scientific far in advance of the rest; how the state fostered these and not others. We have to see not a gradual and general mutual approach of these elements of society, but the joining of contact, first at isolated points, then at more points, finally almost everywhere. The nature of the joining can scarcely be understood unless we remember that it was made in this piecemeal fashion.

The oldest of the sciences was not only the first to enter on a modern period sharply distinct from the old, but also by far the first to be applied in modern times to practical needs. In the distant past astro-

nomy had provided the framework within which time and space were reckoned. In the later Middle Ages it was applied to the new problems of geography and navigation, and from that time onwards it was supported in this task by governments and educational institutions. Prince Henry the Navigator of Portugal formed a research institute which carried on and developed the learning of the old Moorish schools of Spain.[1] Under Charles V of Spain the *casa de contratación* of Seville, which was a government department of commerce, had its school and its examinations, and was an intellectual centre. England for a long time lagged behind the Latin countries. The English Muscovy Company, in its early years, maintained one man learned in the science of cosmography,[2] and a group of its members sponsored the publication in English of Martin Cortes's *Arte of Navigation*.[3] Queen Elizabeth and her ministers gave employment, with no tangible results, to that curious astronomer and geographer, half-magician and half-scientist, Dr. John Dee. The queen's physician, William Gilbert, did scientific work of high importance on the theory of magnetism, including its practical application to navigation; but he worked alone, and he found no more appropriate body to which to bequeath his books and instruments than the College of Physicians. The preface to Richard Hakluyt's

[1] See E. Prestage, *The Portuguese Pioneers* (1933), cap. xiv.

[2] E. Cheyney, *Hist. of England*, i (1914), 315.

[3] See the dedication of Richard Eden's translation (1561).

*Voyages* implies that navigation was not publicly taught in London in his time, and Thomas Fuller, in 1662, wrote: 'Some conceive it would be a great advancement to the perfecting of English Navigation, if allowance were given to read a lecture in London concerning the subject, in imitation of the late Emperor Charles V.'[1]

These words were published in the year of the foundation of the Royal Society. In that movement navigation, as we have already seen, was not neglected. Within a few years King Charles II took under his patronage an endowment for the teaching of navigation at Christ's Hospital.[2] In the *Ordonnance de la Marine* of 1681 Louis XIV ordered that schools of navigation should be set up in all his more considerable seaports.[3] In establishing the office of astronomer royal, and the Greenwich observatory, Charles II had in mind chiefly the problem of correctly ascertaining the longitude at sea: in this he had been preceded by Louis XIV, whose steady support of the researches of Cassini was due to similar motives.[4] The abortive Act of the Irish 'patriot

[1] *Worthies*, cap. viii.

[2] There is a good account of the foundation in E. H. Pearce, *Annals of Christ's Hospital* (1901), c. vi; for further particulars see the references in *Dict. of Nat. Biog.*, s.n. 'Collins, John'; R. Hooke, *Diary* (1935); A. Bryant, *Samuel Pepys, The Years of Peril* (1935).

[3] Livre I, Tit. viii, in Pardessus, *Collection des lois maritimes*, iv (1837), 335. The first French official regulation of this kind was in 1629.

[4] For the scientific side of the question see F. Marguet, *Hist. générale de la navigation, du XV$^{e}$ au XX$^{e}$ siècle* (1931).

parliament' of 1689, for the Advance and Improvement of Trade, ordered the establishment of free schools for teaching mathematics and navigation in Dublin, Belfast, Waterford, Cork, Limerick, and Galway.[1] Sir Joseph Williamson, who was a fellow of the Royal Society and had been secretary of state under Charles II, left £5,000 when he died in 1701 for a school of mathematics in Rochester.[2] In Queen Anne's reign, when the Schism Act deprived the nonconformists of the right to teach in schools, an amendment was included in it which exempted teachers who, using the English language only, taught reading, writing, arithmetic or mathematics 'as far as such mathematical learning relates to navigation or any mechanical arts only'. In the previous year parliament had offered a prize for a method of discovering the longitude at sea, and such offers were renewed until, in 1773, the last instalment of £5,000 was paid to John Harrison for more than forty years' work on his chronometers.

In the great movement of the expansion of Europe, navigation was not the only art which governments and business men tried to have set on a scientific foundation. It is, indeed, not an exaggeration to say that the more enlightened leaders of economic life had a general hope that if they encouraged the accu-

[1] Text in G. O'Brien, *Economic Hist. of Ireland in the Seventeenth Century*, p. 172.

[2] See C. Bird, *Sir J. Williamson, Founder of the Mathematical School* (1894), and *Dict. of Nat. Biog.*, s.n. 'Colson, John'.

mulation of ordered knowledge about the new lands and their resources, at least some of it would turn out to be useful. The Portuguese in the sixteenth century made important contributions to the knowledge of drugs, and they made studies in tropical medicine, in which they were afterwards followed by the Dutch. Spaniards studied the natural history, and especially the botany of their colonies. A long line of famous English scientists found inspiration in the new countries. Thomas Harriot is better known to the world for his excellent report on Virginia[1] than for his eminence as a mathematician. John Banister, entomologist and botanist, was a missionary, who travelled in the East Indies and died in Virginia; Sir Hans Sloane worked in Jamaica; William Sherard, the founder of the Oxford chair of botany, was consul for the Levant Company in Smyrna and made botanical and antiquarian tours in Asia Minor. In the early days of the Royal Society, merchants employed their factors abroad to answer questions for it.[2] A number of seventeenth-century economists advocated the scientific investigation of natural resources, and for this the colonies provided a promising and open field.

Similar instances may be given from the other colonizing nations. The French had scientific travellers from the botanist Clusius, Charles de l'Écluse,

[1] *Briefe and True Report of the New Found Land of Virginia* (1588); reprinted, translated, and illustrated at various dates in the sixteenth century.

[2] Sprat, p. 130.

in the sixteenth century. Early in the eighteenth century, Father Louis Feuillée, a pupil of Cassini, published his observations of all kinds from the Pacific and America. The Dutch, especially in the late seventeenth century, showed a general interest in the natural history of their colonies. One of their famous botanical books was the *Amboonsch Kruydtboek*, the Amboyna herbal, printed in 1741 by the German Rumphius, a soldier and administrator, whom the Dutch East India Company helped for this purpose by providing an assistant and an artist. An earlier administrator, Hendrick Adriaan van Reede tot Drakenstein, governor of Malabar, worked on his great *Hortus Malabaricus* (12 vols., 1678–1703) with a regular staff, which included a doctor, a missionary, native artists, and an advisory committee of brahmins.[1] We have lately had an edition, with an English translation and reproductions of its ample illustrations, of the comprehensive report on the geography, zoology, botany, and mineral resources of Namaqualand made by the scientist who accompanied Simon van der Stel on his exploring mission there in 1685–6.[2]

There was, however, no branch of economically useful knowledge other than navigation which received anything approaching the same measure of encouragement from the state or of educational and

[1] For some particulars of these and other Dutch works see C. Busken Huet, *Het land van Rembrandt*, 3rd. ed., vol. ii, pt. 2 (1898), pp. 67–77.

[2] *Simon van der Stel's Journal*, ed. G. Waterhouse (1932).

material equipment. Science itself was not ready for the task. Technology as it then was, the knowledge of the infinitely various processes of separate industries, could not be conceived systematically as a whole. The widest systematization that was possible was to relate together the processes which were explicable by mechanics, then the most advanced and active of the applied sciences. Hydrostatics became capable of the like use in the eighteenth century, but chemistry lagged behind until the nineteenth. Even in mechanics, clock-work, which was closely related to navigation, made the greatest advances. Thus technology as a whole was far less suitable for systematic study than theoretical science; and the academies could not do more for it, except in the special mechanical sphere, than to amass information and, here and there, to throw out a practical hint. The helplessness of the non-mechanical sciences in the face of practical requirements may be illustrated in various fields. There was an earlier period of about a hundred years, from the middle of the fifteenth century to the middle of sixteenth, when metallurgists were unable to devise a strong enough gun-metal to permit the use of the new and more powerful forms of gunpowder which had been produced.[1] In the eighteenth century the backwardness of metallurgical science was shown by the very slow diffusion of the use of coke in smelting iron. In the process of sugar-refining, in the late seventeenth century, when a

[1] F. L. Robertson, *Evolution of Naval Armament* (1921), p. 71.

cheaper substitute was wanted for the expensive medium, white of egg, nothing was possible except mere trial and error, which led to the use of bullock's blood.[1] Chemistry had much to accomplish before it could solve problems like this.

Nor did the scientific movement lead to any growth of general technical education. Numbers of schools were provided for instructing children in spinning and other industrial arts; but it was left almost entirely to employers themselves to raise the standard of accomplishment among skilled workers. Adam Smith expressed regret that in England the charity schools in his time did not teach the elementary parts of geometry and mechanics, since there was 'scarce a common trade' in which they could not be applied, so as to afford an introduction to the most sublime as well as to the most useful sciences.[2] The few educational foundations that are recorded accomplished little. Sir John Cutler, famous as a capitalist and a miser, endowed a lecturer in mechanics in Gresham College, the meeting-place of the Royal Society. Sprat expected this to lead to an improvement in the mechanical arts; but it yielded only one volume of lectures by Hooke and a chancery suit which the lecturer had to bring in order to get his salary.[3]

[1] Poppe, iii. 153. The same two media were used in refining salt.

[2] *Wealth of Nations*, ed. Cannan, ii. 270.

[3] Sprat, p. 130; Birch, i. 453, 473, 479, 503; ii. 141. The lectures on chemistry given in London in the time of William III, for a fee

A very great improvement does, however, seem to have been made in what was then the most useful medium of technological instruction, namely, in printed books. The academies collected a wealth of information about the processes of industry. Economic historians are beginning to use it;[1] but it still offers them a vast amount of new and exact information. Some of it is still in manuscript, but much of the best is printed in the *Philosophical Transactions*, in Sprat's and Birch's histories of the Royal Society, and in separate books, some of which were issued under the auspices of the Society or with its encouragement, while its records contain references to many independent publications. In quality it varies from really scientific studies like Sir William Petty's on weaving[2] to mere descriptions. Taken as a whole it may be said to provide, in this scattered and unequal way, materials for an encyclopaedia of early capitalist technology. This indeed it literally did provide. When Ephraim Chambers compiled his *Cyclopaedia*, of which the first edition appeared in 1728, he announced on the title-page that he would give 'the definitions of the terms and accounts of the things signified thereby in the several arts, both liberal and mechanical, and

of three guineas the course, must have been attended only by the well-to-do. J. Houghton, *Collection for the Improvement of Husbandry and Trade*, iv (1694), no. 89 and elsewhere.

[1] For instance, Mr. R. V. Lennard in his article, 'English Agriculture under Charles II: the Evidence of the Royal Society's Enquiries' in *Economic History Review*, iv (1931), 25.

[2] In Birch, i. 55 ff.

the several sciences, human and divine'. He was able to do it very competently for the mechanical arts by summarizing the English and French academic publications. An examination of his work, and of the voluminous occasional literature behind it, shows that the already very complex technology of the period had been well surveyed. The only department in which the information seems to fall below the general standard is metallurgy; but there, it must be remembered, much depended on knack, and almost every forge or foundry had its secrets.[1]

It is difficult to make a general comparison of this kind, but the technological literature of England and France shows, from about the time of the foundation of the scientific societies, a marked improvement.[2] There are more handbooks, both translated and original. They are in general better-written, better-arranged, and better-illustrated. In earlier times, and in other countries, there had indeed been some excellent works of this kind. The German metallurgical books of the sixteenth century, the great period of the German mines, were excelled in this later period only in Sweden. Italian writers on machines and engineering had produced valuable and handsomely illustrated books in the days when Italy still led the world

[1] Poppe, *Geschichte der Technologie*, ii. 412, says: 'Die Kunst Stahl zu machen überhaupt ist fast in jeder Fabrik mit besonderen Veränderungen und Handgriffen begleitet.'

[2] A general sketch of the development of technological literature, especially in Germany, is given in K. Karmarsch, *Geschichte der Technologie seit der Mitte des 18. Jahrhunderts* (1872), pp. 857 ff.

in those matters.[1] The improvement in England and France was perhaps partly due to the growth of their manufactures and wealth, and this seems to be confirmed by the fact that the Dutch, who in so many respects were leaders in civilization in the middle of the seventeenth century, had a comparatively meagre output of technological works except in their special domain of drainage and canal-making. No doubt also the better quality of the new books was due to the general tendency to more practical and less pedantic writing; but when all these factors are taken into the reckoning, it remains true that the organized scientific study of technology left its mark on the literature of the subject.

[1] The best are A. Ramelli, *Le diverse et artificiose machine* (1588), and the less beautiful but more business-like book of A. Zonca, *Novo teatro di machine et edificii* (1607, reprinted 1656).

*Additional Note.* Descartes wrote in his *Discours de la méthode*, pt. vi, 'il est possible de parvenir à des connaissances qui soient fort utiles à la vie . . . nous . . . pourrions . . . nous rendre comme maîtres et possesseurs de la nature. Ce qui n'est pas seulement à désirer pour l'invention d'une infinité d'artifices qui feroient qu'on jouiroit sans aucune peine des fruits de la terre et de toutes les commodités qui s'y trouvent, mais principalement aussi pour la conservation de la santé . . .'

For surveys of natural resources see *Memoirs of Sir Robert Sibbald*, ed. Hatt (1932), pp. 74, 95 (Scotland), and E. A. J. Johnson, *Predecessors of Adam Smith* (1937), c. vii (Nehemiah Grew). Appendix A to the latter book gives a list of the items of economic interest in the *Philosophical Transactions* from 1665 to 1776.

# II

# THE ECONOMIC INCENTIVES TO INVENTION

WHETHER the argument of the preceding chapter be sound in detail or not, it cannot be doubted that science and scientists made their contribution to technological progress in our period; but when we ask how they came to make that contribution, we are confronted by differences of opinion. Some historians of technology take the development of science as their main thread of explanation, treating the practical applications of science as appendages, secondary consequences, flowing from the theoretical discoveries.[1] As a method of exposition this has great advantages; it gives a logical simplicity to the story; but it is clearly incomplete. The earliest comprehensive histories of technology had no such single point of view: they treated the history of science in combination with various other departments of history, especially of economic history.[2] They regarded even the most scientific of inventions as devices for satisfying human needs, and, without any attempt to settle general laws of the interaction of new knowledge and new needs, they set down in each case what was ascertainable about the economic circumstances in which

[1] This is the method of the useful *Esquisse d'une histoire de la technique* of A. Vierendeel, 2 vols. (1921).

[2] The best is J. H. M. Poppe, *Geschichte der Technologie*, 3 vols. (1807–11).

each invention was made, and the scientific principles that were embodied in it. Thus the history of technology may be regarded on the one hand as the history of applied science, and on the other hand as a meeting-point of many departments of history, among which that of science is only one.

There is yet a third point of view, which insists on the importance of technological development itself, as distinguished from that of science and that of industry or society. A recent historian, writing of the eighteenth-century inventions of spinning machinery, writes these words: 'The dates of decisive practical achievement were conditioned more largely by the mechanical difficulties encountered than by the conscious selection of particular processes for successive development.'[1] If we look at this sentence microscopically, we shall observe that one set of conditions is positive, and the other negative; the conscious selection of a line of advance is a condition favouring discovery, but the encountering of mechanical difficulties is an obstacle to it. It does not seem felicitous to say that the dates at which practical achievements were reached were conditioned more largely by obstacles than by encouragements; but the words convey clearly enough for ordinary purposes the important truth that at any given moment, technology being what it is, some processes are capable of immediate improvement, but others are not. To understand technological development we must look

[1] A. P. Usher, *History of Mechanical Inventions* (1929), p. 262.

with the eyes not only of the scientist, the economist, and the sociologist, but also with those of the engineer, the industrial chemist, and the other practical men who often solve immediate problems without being aware of their ultimate conditions.

For the scientist, as for the practical man, the problem of how technological progress comes about is concentrated in the moment of invention. Whatever contribution science brings is a contribution to the making of something new. Many books have been written about the psychology of invention, and it has even broadened out into what claims to be a philosophy of technology, down to the present time more ambitious than successful. This body of theory includes a number of different attempts to make use of psychological and philosophical doctrines, but it has, through all its excursions, the constant aim of setting up technology as something with its own nature, incapable of being explained in terms of anything else such as science and economics. It therefore maintains a doctrine, which has also been accepted by some economists, that 'inventive genius is moved in the first instance by non-economic forces'.[1] We need not insist on the word 'genius': it is perhaps better to say that invention starts from non-economic forces. Another familiar way of putting the same point is to say that there is an 'instinct of contrivance'.[2]

[1] F. von Wieser, *Social Economics*, tr. Hinrichs (*s.a.*), p. 46.

[2] The phrase is said to have been first used by Professor Taussig.

Here again we need not insist on the word 'instinct', which has different meanings for different schools of psychology: the point is that at the moment of invention the decisive factor may be mere contrivance, operating in a vacuum which contains neither a process of scientific reasoning nor a consciousness of economic need.

This doctrine, as I have said, is accepted by some economists, at least as an explanation of some, though not of all, inventions; and it has given rise to a useful distinction between 'spontaneous' and 'induced' inventions.[1] No argument is needed to prove that there are some spontaneous inventions, inventions which arise from no necessity and no utilitarian purpose. The simplest example is that of scientific toys. In our period there were many of these: we have already noticed 'Prince Rupert's drops'. This does not contradict what was said in the last chapter about inventions as *partus temporis*. It was no accident that Prince Rupert was experimenting with glass; his drops could scarcely have been contrived in England in any former century; but they were in themselves very nearly a purposeless contrivance. An absolutely pure case of spontaneous invention might indeed be hard to find, and every one knows that, long before inventing became a distinct profession, providing a livelihood, there were induced inventions, inventions deliberately sought for. The distinction is one of

[1] 'Spontaneous' is a much better word than 'autonomous', which is used as an alternative.

degree; in the induced invention contrivance serves to satisfy need. Some process is deliberately selected for improvement, and the moment of invention is not an isolated moment that can be understood by itself, but one of a succession of events in some wider history, which often is economic history.

Economic history is the history of the satisfaction of certain human needs, and what it can do for the history of technology is to explain why there were in each historical period those technical improvements in economic processes which then came into use and no others. It is concerned with much that happens both before and after the moment of invention, and it is not concerned with all inventions. It may ignore mere paper-projects and unused designs. An inventor whose idea is still in his head, or only in a drawing on his table, is as much outside the economic history of his time as if he were living on another planet, or merely destined to live in the remote future. On the other hand, an invention is new in the economic history of one country when it is first worked there, even if it has long been known abroad, or even if it has been known in that country to merely learned or inquisitive people not connected with business.

The most curious example of an invention known but not used is that of silk-throwing machinery. Its introduction into England, in the first of all English power-driven textile factories, was thought so important that parliament, in 1732, made a grant of £14,000

to the proprietor, Sir Thomas Lombe,[1] partly as compensation for the ending of his patent, but partly as a reward. Yet this machinery had been used in Italy from at least as early as 1607, when Zonca engraved it. Zonca's book was used by Dr. Wilkins, and there was a copy of it in the Bodleian, on a shelf accessible to any reader, from at least as early as 1620.[2] For an interval of more than a century, during the course of which the use of this machinery spread to France, it was known to English technologists, but not adopted in England. Clearly it has no place in English economic history before the time of Sir Thomas Lombe; what is relevant to economic history is not the inventing but the adoption and use. For the same reason economic historians need not linger long over the many fascinating puzzles about the exact time and place of inventions. Was printing originally German or Dutch? If that controversy is settled, was it German or Chinese? Were pins invented in England or in Nuremberg? Did the Elizabethan English invent the railways by which coal was carried from the pits, or did they copy them from the Germans?[3] To this

[1] For the whole story see P. Mantoux, *The Industrial Revolution in the Eighteenth Century* (1928), pp. 197 ff.

[2] *Catalogus Universalis Librorum in Bibliotheca Bodleiana* (1620); for the information that the reference A 810 implies an open shelf I am indebted to Mr. R. H. Hill. The book is still in the library, but has been rebound; its history before 1620 cannot be traced.

[3] In 1911 Mr. Rhys Jenkins drew attention to a Nottinghamshire example of 1598 *Collected Papers* (1936), pp. 36–7; and such rails are represented in an engraving in Sebastian Münster, *Cosmographia*

last question we are unlikely ever to find a positive answer. The invention may have been made independently on two or more separate occasions, or it may have been transferred from Germany to England. In either case the economic circumstances which made its adoption profitable were the same.

For economic history the diffusion of new technological devices is as important as their origins. A clear instance is that of the substitution of pit coal for wood fuel in the days when the English forests were becoming depleted. Professor Nef has recently shown in detail how coal helped the introduction of new industries into England in the period from Henry VIII to Charles I; how a more advanced technology, with more expensive processes and larger units of work, brought with it and needed a widening of capitalistic organization.[1] Now many, if not all or almost all, of these processes were not invented in England, but brought in ready-made from abroad; but it was the new economic conditions which led to their being imported then and not earlier or later, and it was their introduction which transformed one industry after another. For our purposes the transfer from one country to another may be even more significant than the first invention.

Economic theorists have made some interesting attempts to work out the place of technological

*Universalis* (1550), p. 9, reproduced in A. Wolf, *History of Science, Technology and Philosophy* (1935), p. 511.

[1] In *Economic History Review*, v (1934), 3 ff.

improvement, whether it be new invention or diffusion, in the general economic process, and practical men of business have thrown out some dogmatic answers to their problem. Theorists had no difficulty in showing that invention had some place in the general process, however that process was conceived. If, for instance, it consisted in the mutual reactions of capital, co-operation, and exchange, then invention must be regarded as a fourth element, acting on each of these in turn, and acted upon by each of them.[1] In so far as it is encouraged by the action of the other elements, it is a response to change, and long ago the classical writers mentioned some kinds of change which are capable of evoking it. Ricardo observed that 'machinery and labour are in constant competition, and the former can frequently not be employed until labour rises' in cost.[2] Now, speaking very roughly, labour rises in cost when production is active and prices are high. Some of the older economists being enthusiasts for technological improvement, seem to have thought there was a harmony between economic progress and technological progress. One of them wrote: 'A period of great commercial activity in England is always a period of inventive activity.'[3] Later writers are more cautious.

[1] This is demonstrated by W. E. Hearn, *Plutology* (1864), pp. 122–3, 167–85, 267–88, to which W. S. Jevons, *Principles of Political Economy* (1905), pp. 93 ff., adds nothing except some generalities about science.

[2] *Principles of Political Economy and Taxation* (3rd ed., 1821), cap. xxxi.

[3] Hearn, p. 287.

Professor Pigou, for instance, holds that 'there is evidence that in slack periods technical devices and improvements accumulate in the sphere of knowledge, but are not exploited till times improve'.[1] It is easy to see how this can be so: the exploiting may cost money which is not available when business is bad.[2] On the other hand, there have been writers who have insisted that technological improvement may also be due to exactly opposite conditions. It may be a response to economic depression. When markets collapse and prices are low, when price-cutting competition sends them lower still, then the manufacturer looks to his costs. It is strange that in the last few years some writers have been surprised and consoled by the fact that for this simple reason mechanization has made great progress. That it would be so might have been foreseen. More than a century ago John Kennedy, one of the great mechanizers of Manchester in his day, reflecting that Crompton's mule was invented during the bad time of the American War of Independence, remarked that 'the greatest improvements have always been in such seasons of depression'.[3]

The upshot of what the theorists and the practical men have to tell us about this matter is then, in the

[1] *Industrial Fluctuations* (1929), p. 44.

[2] The best-known instance is that of Nasmyth's steam-hammer, which he claimed to have invented in 1839 in a depressed period, but which was not used in England until 1843. The evidence in his *Autobiography* (1883) is, however, not absolutely convincing.

[3] *Memoir of Crompton* (1830), p. 66.

words of a contemporary economist, 'that every price change, by creating cost difficulties in certain fields and opportunities for profit-making in others, provides a double stimulus to invention'.[1] The economic history of the seventeenth and eighteenth centuries gives concrete examples of this principle, and indeed gives more than mere examples. It shows, in spite of the defects of our knowledge, the continuous operation of the principle in the economic process in western Europe.

In the age of Newton, we must of course premise, the intensity of inventive activity was much lower than in the technological age into which we have been born. In other words, there were fewer inventions; changes in economic processes were fewer, slower, and smaller. Such changes are in their nature cumulative; one leads on to another, and once change begins to set in the direction of making processes more complex, there must be a widening tendency for more and more processes to come up to the same level of complexity. So in Newton's time things were working up towards the comparatively complex technology of the late eighteenth-century Industrial Revolution.

The way in which one complicated machine led on to another was already the same as it was in the later period. One of the characteristic *motifs* of the indus-

[1] Professor A. Plant, 'The Economic Theory concerning Patents for Inventions' in *Economica*, New Series, i (1934), 38. I wish to acknowledge my general indebtedness to this article.

trial revolution in the textile industries is the alternation of improvements in spinning and weaving. Inventors responded to a scarcity and dearness of yarn by improving the processes of spinning. The improvement went so far that there was more yarn than the weavers could handle, and this new disequilibrium (which involved a price-change) was resolved by improvements in the processes of weaving. Now this alternation, familiar in all the textbooks, is usually supposed to have begun with the great spinning improvements of the eighteenth century. If we turn to the late seventeenth century, however, we find that these improvements in spinning were themselves preceded by improvements in weaving, and also in the other processes in which the thread is used after it has been spun.[1] In Charles II's time the economic journalist Houghton showed Hooke 'the new looms', whatever they were.[2] There was an improvement in the warping of wool, a process preparatory to weaving.[3] In dyeing and finishing processes there were various improvements,

[1] In 1687 Mason of Norwich took out the earliest patent for an improvement in the loom, the device which enabled the weaver to dispense with a draught-boy or draw-boy; but this was an improvement in the draw-loom used for pattern-weaving, not in the plain loom from which most of the English exported fabrics came: R. B. Prosser, *Norfolk Inventions* (1919), p. 10.

[2] Hooke, *Diary*, 10/20 February 1678/9. In 1678 Richard Haines (for whom see below, p. 100, n. 2) and Richard Derham obtained a patent for a spinning-engine; but it does not seem to have been of practical importance.

[3] There is no trace of this among the *Specifications of Patents*.

newly invented or introduced from abroad,[1] and another sign of the rising standard of these is the excellence at this time of the French manuals about them.[2]

If we look further back we see that this vigour in the later processes was in its turn preceded by an improvement, or rather a series of improvements, in spinning. John Aubrey, writing early in the reign of Charles II, noted 'the art of spinning is so much improved within these last fourty years, that one pound of wooll makes twice as much cloath (as to extent) as it did before the Civil Warres. In the old time, sc. Edw. 6 etc. they used to spinne with rocks: in Staffordshire etc. they use them still.'[3] It is not clear what improvement in spinning Aubrey had in mind. Not only was the gradual supersession of the rock or distaff still going on. At much the same time an improved form of the Saxony wheel, with two spindles and two spools, one thread for each hand,

[1] The abolition in 1661 of the Elizabethan and subsequent prohibition of the use of Campeachy wood (logwood) was followed in 1666 by Brewer's introduction of Dutch processes and workmen. For the grant of a patent for making orchil and litmus for dyeing see Privy Council Register, 6 July 1693. It is commonly stated that the use of indigo was restricted until the late seventeenth century; but this appears to be an error (W. H. Moreland, *From Akbar to Aurungzeb* (1923), p. 108, n.).

[2] For a good account of the contemporary French textile inventions see Usher, pp. 253 ff.

[3] Bodleian MS. Aubrey 2. This is from the section 'Mechanicall Arts', in Aubrey's Wiltshire, not printed in the selection ed. by John Britton as *Natural History of Wilts.* (1847). In the margin Aubrey mentions 'Mr. Sam: Ash.' as his informant.

was coming in.[1] But neither of these improvements will explain the lighter thread which Aubrey seems to imply. In one of the minor trades which used woollen yarn we find changes which fit in neatly with these we have noticed. It is said that until about 1660 frame-work knitting required two pairs of hands, but at that time the frame was improved so that one man could work it.[2]

Evidently it is a mistake to suppose that a new era of improvement in the textile industries began in the early eighteenth century; the inventions of Hargreaves, Paul, and Arkwright were merely continuations of a rhythm which began long before their time. There are, indeed, other departments of economic life where there seems to be a much sharper break in continuity. The most striking instance is the almost complete absence of mechanization from the agriculture of those days. The fewness of agricultural machines is a leading fact of the period. Its explanation does not lie on the side of mechanical incapacity. The machines were invented but they were not wanted. In England, for instance, in 1636 Sir John Christopher van Berg took out a patent for a threshing-machine.[3] Thomas Fuller wrote, after the Restoration, that some thirty years before at Stockbridge he had seen a plough which, by the help of engines and some contrivances, could be drawn

[1] J. Horner, *The Linen Trade of Europe* (1920).

[2] J. Blackner, *History of Nottingham* (1815), p. 214.

[3] *Abstracts of Specifications of Patents*, no. 92 A.

by dogs and managed by one man, who in one day could plough nigh an acre of light ground.[1] Jethro Tull, early in the eighteenth century, was devising his horse-hoe, his drill, and his four-coultered paring plough. Yet in the history of how English land was farmed none of these facts is worth mentioning. The overwhelming majority of farmers were satisfied with the older equipment.[2]

Now in England it is easy to account for this indifference to agricultural invention. Farmers had not the incentive to mechanization which has since come from dear labour. From the middle of the seventeenth century labour was cheap and agricultural technique was improved by new crops, not by reductions of the amount of labour used per acre. It was not until the eighteen-twenties that threshing-machines came in earnest, and not until the eighteen-fifties that reapers were more than curiosities.

There were many other countries where the conditions were similar. In 1700, for instance, a threshing-machine driven by water was at work at Erzen near Hameln ('near famous Hanover city'); but we are told that its use did not become general because it was suitable only for large estates where hired labour was scarce and dear, but in that part the ordinary cultivators used only family labour.[3] There were,

[1] *Worthies*, Hampshire.

[2] See Mr. T. H. Marshall's important article, 'Jethro Tull and the New Husbandry', in *Economic History Review*, ii. 41 ff.

[3] Poppe, i. 194–6.

indeed, two great regions where labour was scarce and dear, and in these we find indications that some attempts were made at mechanization. The first was the great Baltic corn-growing area, the old frontier of Europe, where agriculture was an export industry. Here we read of a nobleman of Courland who, in 1670, had a threshing-machine made from his own designs, which did fairly well until it was destroyed by fire nine years later. Some others imitated him; but the great problem was solved differently in that region. It was solved from Denmark to Russia by a change not in technique but in organization. It was solved by depressing the status of the labourers, by forcing them down to serfdom, and so making their labour cheap.

In the other region where agricultural labour was dear, we find the same resort to a special system of organization. This other region was the western frontier of European civilization, America. Here, too, there are traces of the stimulation of invention by the scarcity of labour. The first patent for a mechanical invention issued in America was given in Massachusetts in 1646 for improved saw-mills and scythes, and the tradition of the superiority of American over English corn-mills goes back to the last years of the seventeenth century.[1] But agricultural machinery, though it developed in America before it developed in Europe, was unimportant there, too,

[1] V. S. Clark, *History of Manufactures in America* (1916), pp. 48, 180.

until the nineteenth century. During our period family farms prevailed, and the dearness of labour prevented the development of large-scale exploitation. The English did indeed make various attempts to use convict labour and indentured white labour, but the main population was built up by free immigrants. The only regions in which agriculture was able to expand to the scale of an export industry were those of the sugar and tobacco plantations, where the negro arrived as the *deus ex machina*.[1]

The apparent contrast, then, between the seventeenth century and the nineteenth in the matter of agricultural machinery is explained if we remember that mechanization is a response to certain cost-conditions, and that another way in which it is sometimes easier to cope with such conditions is by changes in human organization. It may be remarked parenthetically that in the history of English agriculture such changes of organization were extremely important from the sixteenth century until the nineteenth, and that the English response to price-difficulties in agriculture is to be found in the rise of money-economy, of which one aspect is the ending of serfdom, and in the various enclosure movements, and the rise of individualist farming. We are

[1] In 1670 John Evelyn presented to the Royal Society a Spanish *sembrador*, a new machine for ploughing, equal sowing, and harrowing (*Philosophical Transactions*, no. 60). In England it had no history, but Spain was the most notoriously depopulated country in Europe. It had, however, been taken there only two years before by the inventor, who was a Carinthian.

not, however, now concerned with questions of organization except when they are directly connected with technological change, to which we must return.

Can we trace any relation between technological development and any cyclical movements of trade and industry in our period? We have seen that the combinations of circumstances which then led to technological improvements were analogous to those which had similar effects when they came about in the course of the so-called business cycles of the subsequent age. Students of the earlier period are, however, by no means agreed as to whether such cycles can be traced in it. Here and there something resembling them has been studied: the international financial crises of the later sixteenth century,[1] the fluctuations of English trade from that time to the South Sea Bubble of 1720,[2] and so on; but the work has been sporadic and imperfect. Even the South Sea Bubble has only recently been examined in connexion with the French Mississippi incident, and the relation of both to contemporary Dutch events is still untraced. From the South Sea Bubble to 1763 the whole subject is in darkness. It is therefore still premature to say whether the crises, which are commonly held to form a series from 1763 to 1931, began much earlier, or whether the earlier crises differed from

[1] Especially by Ehrenberg, *Das Zeitalter der Fugger*, ii. 147 ff.

[2] By Professor W. R. Scott in his *Joint Stock Companies*, especially iii (1912), 463–71.

them in some essential characteristics because of the differences of economic organization.[1]

Provisionally one thing may be said. It seems clear that in the earlier period fluctuations arose chiefly from causes which were not purely economic in the narrowest sense, and especially from the alternations of war and peace. Mr. T. S. Ashton has admirably shown for the period of the Industrial Revolution, how the metal industries in time of war were regularly stimulated, and how they recovered from post-war depression by rationalization and by devising new products to sell.[2] It would be worth while to extend this investigation backwards, and there are some indications that it would yield similar results. Certainly the wars led to a growth of the metal, especially the iron and steel, industries; and in some instances the use of these metals for domestic purposes seems to have relieved 'post-war depression'. I suspect that one reason why the manufacture of Sussex fire-backs expanded considerably in the early seventeenth century was that the foundries had fewer orders for cannon in the peaceful early days of the Stuarts.[3]

[1] This is the view of W. Sombart, *Hochkapitalismus*, ii. 564; of Professor Z. W. Sneller (*Economische crisissen van vroeger tijd*, 1932) and, on other grounds, of Professor Scott, loc. cit. It should be noted that Defoe's excellent description of the alternation of boom and slump in *Plan of English Commerce* (1728), pp. 257–8, is applied only to the wool-trade, not to the general state of trade.

[2] *Iron and Steel in the Industrial Revolution* (1924), cap. vi.

[3] There is not sufficient information in E. Straker, *Wealden Iron* (1931) to confirm this view, but the evidence on pp. 61–5 goes some

Whether this method of recovering from depression was as common then as in the later eighteenth century and the nineteenth we do not yet know. It is, however, clear that the virtual protectionism of war was already normally followed by a demand for legislative protection after the return of peace. Thus in 1719 one of the features of the British tariff reforms which modernized industrial protection was the granting of special protection to the metal industries, and this came five years after the end of the wars of Louis XIV.[1]

Something may be said here about the direct effect of military needs on technology. Some inventions were made for the convenience of armies, not of ordinary industrial production, such, for instance, as the portable corn-mills of which various types were made in the sixteenth century.[2] Some of them were afterwards used for other purposes, like the boring-machines which were used first for cannon and afterwards for the parts of steam-engines. The

way in that direction. *Mutatis mutandis*, I make the same guess about imported fire-backs.

[1] It is worth noticing that the Huguenot physicist Desaguliers is said to have revived, in the same year, discussion on the possibility of using iron for bridges. This led to no immediate result. A wrought-iron bridge was unsuccessfully attempted at Lyons in 1755; but the famous cast-iron bridge of Abraham Darby over the Severn, projected in 1776, was the forerunner of nearly a hundred made in England between the American War of Independence and the French war of 1793.

[2] See the 'Note of Sundry Sorts of Engynes' endorsed by Burghley in Brit. Mus. MS. Lansdowne 101.

military demand was in several ways more effective than that of industry. It was more concentrated: the largest single purchases ever made in the early capitalist period were those for armies and navies. It was not limited in its amount by the necessity of selling at a profit. It was paid for by the compulsory taxing-powers of the states. It also required a greater uniformity in the goods supplied. Thus it promoted for several different reasons standardization, the characteristic method of mass-production. Professor Heckscher has pointed out that, when the government of Louis XIV attempted to reduce the weights and measures of France to uniform standards, it had only one success, and that was in co-ordinating the measures used in the naval arsenals.[1] The most famous example of standardization was that of the arsenal in Venice, with its stores of spare-parts which could be fitted to any ship. When the Dutch became a great naval power, their shipwrights used similar methods, and the progress of science helped them by supplying more accurate and handier measuring tools.[2] War again, as we have seen, supplied the strongest motive for the efforts of the states to promote scientific navigation, and all its subsidiary needs like the charting of the seas.

We have now seen that economic conditions under

[1] *Mercantilism* (1935), i. 117.

[2] For the influence of naval requirements in promoting uniformity in the build of merchant ships see J. E. Elias, *De vlootbouw in Nederland, 1595–1655* (1933), pp. 92–3.

early capitalism tended to promote technical improvement in the same ways which have since become familiar in every branch of production and trade. We have also seen that they were in that age operative only in narrower fields. The economic system of which technological progress, so conditioned, is one of the notes, was spreading from certain nuclei. Within each of its favoured regions the new system was already highly developed. Far back in the Middle Ages, in a peasant society producing mainly for subsistence, there were already in some towns some industries which manufactured on a large scale for distant sales, under capitalist control and in competition with others, using technological improvement as one of their instruments. Whether imported or invented, the improvements tended to increase the scale of the units of production, and so the scale of the financial units. They increased the total productive power, and so they intensified the competition for markets. They made industry liable to fluctuations, and while, as we have seen, they were fostered by depression, they alone could supply, and they in turn accentuated the over-production of confident periods.

The economic history of technology is thus clearly traceable in connexion with the history of trade fluctuations and of organization. It may be further illuminated for the general history of prices. The historians of prices are lighting up many of the dark places of economic causation. They are drawing

more firmly the main outline of economic evolution, so far as it can be expressed in terms of the relative values of money, commodities, and services. Before we can understand these matters fully we must learn much more about some other branches of economic history, especially about population; but some facts, if not yet explained, are established definitely. Every one has known now for a long time that in the earlier phase of the early capitalist period there was a 'price revolution'. Its general nature was a great rise in prices, and its social effects were felt all over western and central Europe, spreading northwards and eastwards from Spain, mainly in the sixteenth century. There is still doubt about the causes of the change; but for the moment we may be content to say that it was caused by the impact of great new supplies of the precious metals upon societies in which their use was already expanding, and where, by means of the expansion, natural economy was giving way to money economy, business economy, income economy. In the countries other than Spain, the precious metals were acquired for the most part by export industries (including the 'invisible' export industry of shipping), and the rise of these new export industries meant a growth of capitalism. A clear, indeed too clear, picture of the social effects of the price-revolution has become familiar. It was a period of expansion, and so, though like all periods of inflation it was detrimental to the creditor-classes, it favoured the borrower, especially the industrial borrower.

Therefore, from this side again, it favoured the rise of capitalistic industry. In several ways it was favourable to technological progress. Prices were rising and production expanding, so labour was scarce and dear. On the other hand markets were expanding, so there was a further motive for increasing output.

For some of Adam Smith's predecessors the history of prices consisted of this one incident. They did not see what is becoming familiar to us, that the sixteenth-century price-revolution was followed by another, though less abrupt, price-change in the reverse direction. From about the middle of the seventeenth century the great rise in prices had worked itself out. The graph of price index-numbers, after climbing for over a century, at that point reaches what the French call *un palier*, a landing; prices fell or remained fairly stable until the late eighteenth century. We must expect in this phase of decline or steadiness the ending or even the reversal of the phenomena of the earlier phase. Generally speaking contraction succeeded to expansion. The pace of exploring and overseas settlement slackened. The price-landing, whatever its ultimate causes may be, expresses a rise in the value of the precious metals. They had become harder to get, and therefore international competition for them was intensified. Mercantilist thought entered on its protectionist phase. There were stricter navigation laws; protective tariffs; wars. There is no need to elaborate this, because in recent years we have all seen

another and swifter downward price-change penetrate the whole social and economic structure of our world. We have witnessed its effect on rationalization and technology, and we are therefore able to look for the like effects in the earlier period.

As to this it seems that each of the two phases in the history of prices was marked by technological advance, but that the change in economic climate brought about a corresponding change here too. It might be maintained that, in spite of some cardinal inventions like the stocking-frame, the ribbon-loom, the Italian silk-throwing machines, the first phase showed on the whole less inventiveness than the second. Unfortunately there does not seem to be appropriate evidence to decide this question one way or the other. There can, however, be no doubt that whether we can or cannot make a quantitative distinction, there were changes in the quality and direction of technological improvement. We have already seen that the work of the great scientific academies in England and France came almost at a definite point of time; and that point of time can be described as the earliest moment by which it was possible to organize such a response to the new phase of prices. This is indeed obvious: the Académie des Sciences was the intellectual side of Colbertism. Again, technological improvement was most active in the second half of the century in those industries in which there was international competition. These were the export industries, which each state now tried to foster

in order that its dependence on imports might be lessened, and its exporting power increased. Five industries which made notable technical advances—sugar-refining, distilling, glass-blowing, silk, tobacco—all belonging to this class. Book-printing, timber-sawing, and lead-smelting were almost on the same footing; and paper-making may be mentioned as another industry in which, while the English and the Dutch fought the French with import and export prohibitions, they were also busily at work experimenting, ultimately with success, to produce a rag-cutting machine.[1]

The greatest trades involved in this rivalry were the textile trades, and one of the greatest single manufacturing export trades existing in Europe when the turn in prices came was the English cloth trade. This great trade was more or less on the defensive throughout the phase of falling and stable prices. We should therefore expect to find in it technological activity; and we do find it. The improvements which have already been mentioned coincide in time pretty closely with periods of depression. They have another characteristic which reflects the economic conditions of the period. Many of them helped British industry to change over from the manufacture of luxurious articles to mass production for cheapness and utility. Instead of making silk stockings by the thousand, Nottingham now made worsted stockings by the million. The huge military demand was for the arms,

[1] Poppe, ii. 201–8.

clothing, and food of the common soldier; and we must note that the great growth of armies came in the reign of Louis XIV, that is, once more, in the course of the second and reverse price-revolution. During that same period the English export industries were preparing the way for England's subsequent industrial supremacy by turning over to the mass-production of cheaper articles, textile and other. To an extent which brought new evils with it they were seeking overseas markets; but the concentration of England's resources in manufacture at the expense of agriculture did not begin until long afterwards. In the eighteenth century, so long as prices were low and agricultural labour was cheap, the standard of living for the poor was rising. More and more people in town and country drank tea and ate wheaten bread. It is to be hoped that we shall soon know this more exactly and more certainly; but we do know already that until the 'golden age of the English agricultural labourer' in the reign of George II, the diet, clothing, housing, and amenities of most classes of English people were on the whole improving. Thus the production of cheaper articles for wider consumption in the home market was a new kind of expansion, automatically pointed out by the price-depression itself, affording a refuge from the competitive conditions of the old overcrowded markets. If we did not know of the social calamities which accompanied the next great phase of rising prices, we should look back on the end of the early capitalism

as a time when technological improvement was bringing to England prosperity. It was, at any rate, a time when the need for new pathways to prosperity led to the exploration of technical improvements.

*Additional Note to p. 48 above.* In 1792 one of the measures suggested by Addington for gradually reducing the slave-trade was a premium on the introduction of agricultural machines in the plantations (R. Coupland, *Wilberforce* (1923), p. 165).

# III

# SOCIAL AND ECONOMIC ASPECTS OF SCIENCE

IN the sixteenth and seventeenth centuries Western civilization was being transformed by two great movements: the economic changes which we sum up as the rise of capitalism, and the changes in knowledge which we sum up as the scientific movement. Each began long before that time, and each has lasted long after it, but in that period both were triumphantly proceeding, and it was then that our civilization entered on its present phase, in which the power of science in action has carried it over all the world. Economic historians have asked and answered many questions about the relations of the two movements. They have traced the influence of science on technology and on economic life, the influence of economic needs on education, the influence of new wealth and world-wide trading on knowledge and beliefs. Whichever of these lines of inquiry they follow, sooner or later they come upon the question, What light does economic history throw on the history of the scientific movement itself? Some of them hold that the origin and nature of that movement are best understood if they are explained in terms of economic history. I wish to examine this theory, especially in its application to the glorious advances of science in the late seventeenth century.

We are fortunate in having a very clear statement on the subject in an article which has attracted much attention in recent years, though rather among scientists than among historians, by Professor B. Hessen.[1] From the point of view of the historian, indeed, the article has serious defects. Professor Hessen makes many mistakes of historical fact. I do not propose to discuss these mistakes.[2] I have, as far as possible, corrected them for myself, and what I wish to discuss is the main thesis of the article. If Professor Hessen, who is a physicist, had found as a collaborator a trained historian, he would have been able to eliminate some crudities from his article; but I do not suppose that he would have modified the main lines.

I do not intend to deal with the whole of his argument, some parts of which depend on scientific opinions which I cannot pretend to criticize. It attempts to correlate five different aspects of Sir Isaac Newton's work and times, or rather two aspects of his times and three of his work. On the one hand, there are the social movements of England during

[1] 'The Social and Economic Roots of Newton's *Principia*' in the co-operative volume, *Science at the Cross-Roads* (1931).

[2] It is worth while to point out in a footnote one which might otherwise give unnecessary trouble to a reader of Dr. Hessen. He ascribes much importance to the writings of Richard Overton, about whom, he says, 'one cannot find a single word . . . even in the most complete biographical Encyclopaedias' (p. 31), although there are four columns about him by Sir Charles Firth in the *Dictionary of National Biography*. Interest in Overton was revived by the work of Eduard Bernstein, translated with the title, *Cromwell and Communism* (1930).

his lifetime and his personal social position in the English middle class. On the other hand, there is first Newton's cosmology; next, there are his fundamental doctrines in mechanics; lastly, there is the view of historical change implied by the static universe of his cosmology. 'Newton was the typical representative of the rising bourgeoisie, and in his philosophy he embodies the characteristic features of his class.'[1] This accounts, according to Professor Hessen, for the fact that 'those materialistic germs which were hidden in the *Principia* did not grow in Newton into a fully formed structure of mechanical materialism'. It accounts, in particular, for his failure to anticipate the views of Friedrich Engels on the interconnexion and hierarchy of all forms of matter.[2]

On the historical side this reasoning appears to me not altogether convincing. Newton may perhaps have been typical of a certain class, though I doubt if the class-structure of England in his time has been studied carefully enough for us to say so with any certainty. If he was typical of the rising *bourgeoisie*, he was typical of its very mixed origins. By birth he belonged to the declining yeomanry: his heir-at-law was a labourer. From that class Newton escaped to the stability of an ancient university, and from that again, through the patronage of a great nobleman, Lord Halifax, to a well-paid official place in London. Among his acquaintance was another great thinker, John Locke, whose career was in some ways similar.

[1] p. 33. [2] pp. 43 ff.

Of similar origin and education, more closely dependent on a noble patron, but also in the end established in the service of the Crown, Locke too was a rising bourgeois. It may be conceded that Locke, whom Professor Hessen mentions, substantially agreed with Newton about the universe. Another person who agreed with their main intellectual positions was Robert Boyle. Boyle was the son of the most conspicuous *nouveau riche* of his age; and if his rank was that of an aristocrat, he may yet be justly regarded as a member of the new *bourgeoisie*. No one has, however, yet gone through the names of all the thinkers of the period to discover whether the typical bourgeois all agreed, and the rest, whoever they were, did not.

I doubt if that research would be worth making, partly, as I have said, because we know very little about classes under early capitalism, and partly because of a view about the relation of biography to the history of science which I shall explain later.[1] It appears to me that the real strength of Professor Hessen's case lies, not in these generalities, but in the detailed arguments which precede them. There is one section of his article, the second, which I regard as the best available statement of the view that 'the brilliant successes of natural science during the sixteenth and seventeenth centuries were conditioned by the disintegration of the feudal economy, the development of merchant capital, of international maritime rela-

[1] See below, p. 87.

tionships, and of heavy (mining) industry'.[1] Professor Hessen surveys the economic conditions of the time, and then gives a list of four groups of technical problems, which he introduces with the words, 'Thus the development of merchant capital set transport the following technical problems.'[2]

The first list of problems concerns transport, and for its solution each problem requires the study of some branch of physics, for each, in Dr. Hessen's words, 'physical pre-requisites are necessary'. There is the problem of increasing the capacity and speed of ships: this requires investigation of the general laws of displacement and the like—in fact of hydrostatics. There are the problems of the buoyancy and stability of ships, of their responsiveness to direction, and ease of manœuvre: here hydrodynamics is needed. There is the problem of determining position at sea, and that depends upon the mechanism of the heavens, chronometry, the knowledge of tides. Lastly, there are the problems raised by inland waterways, canals, and locks; to these, again, various parts of hydrostatics are relevant.

After these transport problems come those raised by the development of war-industry and of money. Dynamics is useful in the raising of ores from depths; aerostatics in the ventilation of mines; hydrostatics and aerostatics in pumping and water-conducting for mines and other purposes; aerostatics also in smelting with an air-blast; mechanics generally in the

[1] p. 5. [2] p. 8.

extracting of metals from ores, in rolling and cutting machinery. Finally, the whole science of ballistics developed in this period for the purposes of artillery and other fire-arms.

At each step in this enumeration Professor Hessen mentions some of the important names and discoveries of the period; but he does not do more than give them as illustrations. Here he is concerned only to prove that 'the scheme of physics was mainly determined by the economic and technical tasks which the rising bourgeoisie raised to the forefront'.[1] Not only was progress made in these two centuries in each of the subjects which have just been mentioned; but when Professor Hessen goes on to analyse the contents of Newton's *Principia* and 'consider in what interrelationships they stand with the themes of physical research of the period',[2] he finds a 'complete coincidence of the physical thematics of the period, which arose out of the needs of economics and technique, with the main contents of the *Principia*, which in the full sense of the word is a survey and systematic resolution of all the main group of physical problems'.[3] This conclusion, surprising to those who judge the book by the geometrical form of its exposition (though to Professor Hessen that itself is a mere vesture), is reinforced by the facts of Newton's life. He was 'not a learned scholastic divorced from life, but in the full sense of the word was in the centre of the physical and technical problems and interests of

[1] p. 17. [2] p. 24. [3] p. 26.

his time'. He was warden and then master of the Mint. In 1669 he advised his young friend Francis Aston on his travels abroad to observe everything of technological interest.[1] In short, he was not 'an Olympian standing high above all the "earthly" technical and economic interests of his time, and soaring only in the empyrean of abstract thought'. In his case the distinction between pure and applied science can thus be explained away; the 'independence' of science vanishes; and if it is so in his case, it must be much more so, we are left to infer, in others.

For a reason which I shall explain later,[2] I do not allow that these biographical particulars are so important as they appear to Professor Hessen; but it will be well before going further to see if his account of them is correct. We may begin by making him a present of two further pieces of evidence on his side. Newton gave advice on a reform of the curriculum of the navigation school at Christ's Hospital, and in September 1697 he took part as a governor in the visitation of the school to see the effect of the reorganization.[3] Mr. A. V. Judges has recently discovered that in 1709 Newton became a deputy-governor of the Mineral

[1] p. 24. This letter which was written before, not after (as Professor Hessen says), Newton received his professorship, is printed as App. I in vol. i of Sir David Brewster's *Memoirs of the Life of Newton* (1855). [2] See p. 87 below.

[3] E. H. Pearce, *Annals of Christ's Hospital* (1901), pp. 123–4. Newton's interest in education is also illustrated by his scheme for reorganizing the teaching of the Cambridge colleges printed from his manuscript by W. W. Rouse Ball in *Cambridge Review*, 21 October 1909.

and Battery Works Society.[1] Neither these facts nor any of the others are, however, relevant to Professor Hessen's case. Newton went to the Mint in 1696, at the age of fifty-four; and it is a commonplace with his biographers that almost all his scientific work was done before he was forty-five. The one piece of evidence which can be adduced to show that during his great creative period he was actuated by an interest in technology is the letter to Francis Aston; and, oddly enough, if rightly used, this document tells not in Professor Hessen's favour, but against him. The first part of it is in the vein of Polonius's advice to Laertes on a similar occasion. Newton then gives his scientific advice. If he had been a keen and competent promoter of technological observation, he would have recommended Aston to use the excellent instructions to travellers written by Boyle and published only a year or two before in the *Philosophical Transactions*.[2] He did not do so, but instead threw out a few casual scraps of advice which indicate no greater concern with practical affairs than might be expected of any educated man.[3]

[1] *Council for the Preservation of Business Archives. First Report of the Committee* (1935), p. 5. See also the fuller account by D. Seaborne Davies in *Economic History Review*, vi (1936), 209 ff.

[2] Nos. i, ii, xi, xviii, xix; reprinted separately 1692.

[3] This view seems to be confirmed by what we know of Newton's library. Lists of his books are given in the sale-catalogue of the *Libraries of Mrs. Anne Newton and Tycho Wing* (1813), and in R. de Villamil, *Newton the Man* (1931), in both inextricably mixed with other books which were not his, but still permitting this conclusion.

Once again, however, there is no need to insist on the small points. It will be enough for our purpose to keep to the main contentions. I do not deny or doubt that many of the principles worked out by Newton and his predecessors were required for the solution of problems of transport, mining, and metallurgy. Dr. Hessen, indeed, admits that they worked out some questions which did not bear on these problems; but he admits it grudgingly. In an unobtrusive note he has something to say about optics.

'Optics also began to develop during this period, but the basic investigations in optics were subordinated to the interests of maritime navigation and astronomy. It is important to note that Newton came to the study of the spectrum by way of the phenomenon of the chromatic aberration in the telescope.'[1]

But there was a great deal in optics that had nothing to do with the telescope. Long before Newton's time progress was being made in optics for two reasons connected only in a very roundabout way with the rising *bourgeoisie*. The first was utilitarian, to be sure, the desire to correct defects of human eyesight: spectacles were invented in the fourteenth century. But though the desire to see was utilitarian, it was not characteristic of one age rather than another; and if the second reason was utilitarian, then everything is utilitarian, for the second reason was the improvement of the art of painting. The study of perspective

[1] p. 21, n. 1.

is a part of optics, and it was carried far by the painters and the writers on art in the sixteenth century.[1]

The subject of optics has thus brought to our notice two stimuli to scientific work to which Professor Hessen pays little, if any, attention. I do not suggest that this is an important defect in his treatment of the history of physics; but any well-proportioned treatment of the scientific movement as a whole would have to allow a great influence to these two stimuli. Like the study of eyesight, medical studies in general shared in the rapid growth of knowledge from the sixteenth century; the doctors were prominent in the academies; and medical studies were not divided by any hard-and-fast line from other branches of science. The microscope stands in much the same relation to optics as the telescope; but the microscope was as yet mainly used for biological investigations, and these were spreading outwards from the study of human anatomy and physiology to include vegetable, animal, and insect life, and, from the late seventeenth century, bacteriology. By that time medical studies had joined hands with chemistry and physics; the First Part of Boyle's long treatise on *The Usefulness of Experimental Natural Philosophy* (1663–71) is almost entirely medical.[2] In the seventeenth century medical studies were

[1] For instance, in the *Trattato della pittura*.

[2] It may also be noted that the folio volume of translations of the works of the German chemist Glauber, who made many suggestions for economic and technological improvements, was published (in 1689) by Boyle's protégé, the physician Christopher Packe.

as highly esteemed by scientists as they have ever been. Now, the brilliant progress of medical studies may have been in an indirect way 'conditioned' by the early capitalist society. They were aided by the other studies which are alleged to be so conditioned; and some of the branches, like tropical medicine, existed only because of the changes in the physical environment of the spreading Western civilization. But no one can deny that the simple impulse to inquire into the means of prolonging life and curing diseases is primary, independent of particular conditions. It is not the same as the economic motive. The two may interpenetrate; either may reinforce the other; but, on the other hand, they may conflict. What we may call the technology of healing has its own history, and its own relation to the scientific movement, parallel to and co-ordinate with that of the technology of wealth-getting.

If we turn now to the fine arts and consider what was their relation to the scientific movement, we find a third separate and co-ordinate stimulus, resembling, but differing from those imparted by the art of healing and the other 'useful arts'. We cannot, indeed, draw a line between the fine arts and the useful arts. Architecture straddles the frontier, and so do the minor decorative arts; the designing and making of textile fabrics may, as in the tapestries of this period, attain a great height of artistic merit. Much stress is often rightly laid on the influence of the technological requirements of these applied arts upon the scientific

movement. Sixteenth-century Italy, seventeenth-century England and France added much to the knowledge of mechanics in order to perfect their cranes, their excavators, their machines for traction, their methods of building. Their classification and testing of timber and building stones were of use to mechanics, geology, botany. In the same way, chemists worked for the dyers. Now, we may be tempted to say that these are only instances of the economic impulse to scientific investigation. We may be tempted even to extend this explanation to the similar influence of the fine arts. These, too, have their technology. The painter has his pigments, and he may well work at their chemistry. In the same way the pneumatic and mechanical knowledge of the late seventeenth century was put at the service of musicians by the improving of organs.[1] Nevertheless, art, as such, is outside the economic sphere. However closely we identify the technique of artistic creation with its essence, we can never make the beauty of a thing identical with its usefulness; we can never, in short, do away with the difference in kind between art and utility. If we could do so, then we could extend the economic interpretation of the scientific movement to include all the stimuli which it derived from the arts. There are, indeed, many historians in

[1] The extreme instance was the 'archiviole' exhibited to the Royal Society on 12 October 1664, and invented in France twenty years before: it comprised both an organ and a concert of five or six viols.

our time who are engaged in showing that the arts are conditioned by social environments, and some of them, more or less explicitly, in this way try to conjure away the uniqueness of art. But even if they subsume art under the notion of organic life, they admit that when it does arise there are such things as beauty or the specific qualities which distinguish works of art from products which are not works of art. And it must be agreed that an impulse to scientific thought, if it arises from mere speculation about the nature of works of art, is radically different from an impulse that is derived from the desire to provide objects of utility.

Now, it happened that, even if the instances I have already given from optics and elsewhere are open to dispute, there was one stimulus indisputably of this nature which made a very important contribution to scientific thought in the sixteenth and seventeenth centuries, as it had done long before among the Greeks. This was the study of the theory of music. Even in the elementary mathematics which is taught nowadays to schoolboys it has left one relic: every text-book of algebra has its chapter on harmonic progressions. Descartes wrote an *Abrégé de la Musique*. Music did not merely draw attention to the sciences that were useful for making organs, and to acoustics in general. What is far more important, it had much to do with fixing the predominantly mathematical method of seventeenth-century science. It was one of the sources from which there ran down

to Newton the belief that primary qualities were more real than secondary, the belief that God 'ordered all things in measure and number and weight'.[1]

So far, then, in examining the driving-forces which actuated the scientific movement, we have found not one but three, not merely an economic impulsion, but two others radically independent of it, one from healing and the other from the arts. To be exact, we have found four impulses, for Professor Hessen throws together in one the economic motives, whether they operate in the arts of peace or in those of war. In the days of the mercantile system it was common enough, as it is in our own day, to talk as if war were an instrument of economic progress, and as if commerce were an auxiliary of international rivalry; there were trade wars and there were wars for trade. None the less, the economic man, and man the fighting animal, are two distinct abstractions; their motives may interpenetrate; either may reinforce the other, but they may conflict. This is another difference that cannot ultimately be resolved: the stimulus to science from

[1] The Wisdom of Solomon, xi. 20. There is a link between elementary mathematics and one of the lowliest forms of music in the art of change-ringing. According to Fabyan Stedman, *Tintinnalogia* (1671), p. 2, this art was not known fifty or sixty years earlier. From this book and his *Campanologia* (1677) it is clear that change-ringing was popular in Cambridge, where Stedman lived, with members of the university, and connected with a knowledge of permutations. See also J[ohn] W[hite], *A Rich Cabinet with Variety of Inventions*, 5th ed., 1677, which from a reference on p. 138 appears to have been written in 1653, and has at the end, with separate paging, 'Exact Rules for Ringing all Sorts of Plain Changes'.

the desire to succeed in war is not identical with that from the desire to enjoy and create. They came into conflict in England and in France in the time of Louis XIV.[1] It might seem appropriate to give here a story about David Gregory of Kinardie who, in the time of Queen Anne's wars 'employed his thoughts upon an improvement in artillery, in order to make the shot of great guns more destructive'. Newton, we are told, 'was much displeased with it, saying, that if it tended as much to the preservation of mankind as to their destruction, the inventor would have deserved a great reward; but as it was contrived solely for destruction, and would soon be known to the enemy, he deserved to be punished and [Newton] urged the professor [Gregory's son] to destroy it, and if possible to suppress the invention'. The authority for the story is, however, very dubious: it does not appear until eighty years after the event.[2] In any case we do not need Newton's word for it that the military motive is distinct from the economic. We must distinguish four channels by which science was actuated from outside: from economic life, from war, from medicine, from the arts.

We are beginning, but only beginning, to see what complex interactions are cloaked by the statement that scientific progress is conditioned by the state of society. So far we have been considering only the

[1] See above, p. 17.

[2] It is given on the authority of the philosopher, Thomas Reid, in C. Hutton, *Mathematical and Philosophical Dictionary*, i (1796), 557.

thematics of science, its subjects, what it is about. But science is not merely the study of certain subjects: it is study by certain methods; and the development of its methods is at least as vital a part of its history as the changes in its choice of subjects. If we ask what were the characteristic methods of the scientific movement of the sixteenth and seventeenth centuries, we are met by an answer which, at first sight, seems to explain them altogether on economic lines; and when we examine this answer, we find once again that it is only a fragment torn from the true answer, while that true answer has in it a paradoxical factor altogether unlike any of those we have yet considered.

One of the results of the studies of the last generation or two has been to smooth away the sharp contrast that used to be drawn between medieval scientific method and that of the following period; but this is almost altogether because the beginnings of the new methods have been traced back much earlier, not because the nature of these methods themselves has come to be differently understood. They were, as scientific methods always are, far from simple. Three of their important characteristics were that they were experimental, that they were quantitative or mathematical, that they were consciously independent of authority. These three elements alone, to say nothing of others, formed a subtle and unstable compound, varying strangely with changes of time and place; but they themselves are not hard to understand, and their place in the history of thought is well recognized.

Now, if we ask where the first of these elements, the experimental method, came from, we may first notice that it was regarded by those who used it, from the time of Galileo and Bacon, as novel. They were not the first to challenge authority; but they thought they were the first to do it by using this method, and when Englishmen, long after that time, still talked about 'the new philosophy',[1] they meant experimental science. Historians have held that experimentation was taken over into science from art and mining.[2] It would be more accurate to say that it was taken over, not once and for all but by long-continued contact, from art, from mining, and from the skilled handicrafts in general. We can see this happening if we look in the diaries and correspondence of the scientists and see how they visited workshops, talked to artificers, wrote descriptions of industrial processes, used and adapted tools. Trial and error, verification by putting a theory into practice, which had always been the everyday procedure of craftsmen, became the everyday procedure of scientists.

The scientists were not all equally good at learning in this way. John Evelyn's project of a general history of trades never got very far, and one of the

[1] Wallis, in the reminiscences quoted below, p. 88, n. 1, states the relation of the term to Galileo and Bacon. It is used by Houghton, *Collection for the Improvement of Husbandry and Trade*, iii, no. 49. Boyle, in *Works* (1744), iii. 136, contrasts the 'new philosophers' with 'meer chymists' and 'meer scholars'.

[2] M. Weber, *General Economic History*, p. 368.

reasons was, he wrote, 'the many subjections, which I cannot support, of conversing with mechanical, capricious persons'.[1] But Evelyn was more fastidious than most men, and the experimental tendency, from Bacon onwards, was closely connected with the mechanical arts.[2] Boyle, who was Bacon's most faithful follower, made it his business 'to carry philosophical materials from the shops to the schools'.[3] He considered that 'in many cases a trade differs from an experiment, not so much in the nature of the thing, as in its having had the luck to be applied to human uses, or by a company of artificers made their business, in order to their profit; which are things extrinsical and accidental to the experiment itself'.[4] He gave many convincing instances of ways in which craftsmen could improve the 'naturalist's' knowledge, such as their ways of distinguishing what they call the goodness or badness of the things they handle,[5] or their observation of the effects of time and the changes of seasons and the weather.[6] None of his contemporaries wrote at such length about this matter, but that was because they took it for granted: Hooke, for instance, constantly took counsel with skilled craftsmen.

Science took over from economic production more

[1] To Boyle, 9 August 1659, in Boyle, *Works*, v. 397. Descriptions of trades were part of the Verulamian design.

[2] How closely they were involved in Bacon's thought may be seen from the passages indexed under 'Mechanicae artes' in Fowler's edition of the *Novum Organum*.

[3] *Works*, ii. 139.

[4] Ibid. iii. 149.

[5] Ibid. iii. 168.

[6] Ibid. iii. 169.

than its procedure; it caught also something of its spirit or temper. The scientists and the men of thought generally, who had been prone to elaboration for its own sake, to impressive mystifications, became, as we say, business-like. In their language and habits of thought they became precise, economical of effort. They fitted their means to their ends, and always kept a purpose in sight. In all this they resembled the men who were making or selling things for money; and this was due, at least partly, to the influence of such men. The Rev. Dr. Wilkins, in the preface to his book on mechanics,[1] tells the story of the philosopher Heraclitus in the tradesman's shop, and remarks of 'those common arts which are so much despised' that 'though the manual exercise and practice of them be esteemed ignoble, yet the study of their general causes and principles cannot be prejudicial to any other (though the most sacred) profession'. He need not have been so apologetic. If the search for perpetual motion and the philosopher's stone, in which he and his contemporaries still engaged, were relinquished by the end of Newton's time for something better, it was partly due to the positive, practical spirit of the business man. Indeed, this spirit even helped science to hold fast that part of its method which seems at first sight most high and abstract—the mathematical part. It has long been recognized that the introduction of rational accounting in business in the later Middle Ages was another

[1] *Mathematical Magic* (1648).

result of the habit of quantitative thinking which was married to experimentation in the work of Galileo and Newton.[1] Science was applied in business; we must not forget that business was applied in science.

Scientific method was thus shaped and sharpened by what it took over from the arts and crafts and from the practice of merchants. But the artists and craftsmen and merchants from whom these lessons were learnt were not scientists; to become scientific their method had to be combined with something else. It was grafted on to the various methods already in use for the investigation of the universe; and the recent work of historians of thought has emphasized the continuity of these methods, the survival of medieval philosophy and science in the intellectual structure of the new discoverers. Was there any other source outside science and ordered thought in general (including theology), in addition to economic life and the arts, from which scientific method was refreshed and corrected? Indeed there was, though for a very simple reason subsequent thinkers, especially scientists themselves, have been blind to its presence. It was religion. Religion is often supposed to have been antagonistic to the progress of science. Every one knows that Galileo was persecuted by the inquisition;

[1] Simon Stevin, the great writer on mechanics, who had himself been in a merchant's office, in advocating the use of the merchant's method of book-keeping by governments, wrote that, although invented *in barbaro saeculo*, it was worthy to be reckoned among the liberal arts and was as useful as any other invented in Italy. (*Hypomnemata Mathematica*, ii (1605), 11.)

and if this is counterbalanced by the fact that many of the scientists, Catholic and Protestant, were ecclesiastics and enjoyed preferment, there still remains the more serious consideration that in themselves, apart from the fortunes of this man or that, the two activities, science and religion, were drifting apart. The metaphysical implications of Newton's cosmology were found, after his time, to be incompatible with the accepted theology, and there came to be a conflict between religion and science.[1] Some historians of science, therefore, regard as living and progressive only that part of the thought of Newton and his precursors which was afterwards taken over by deistic and atheistic writers; the rest they treat as traditional dead matter, carried along by Newton without examination. We have seen Professor Hessen explaining why the materialistic germs in the *Principia* did not grow in Newton into a complete materialism.

This way of thinking is unhistorical. If we take the works of the seventeenth-century scientists as we find them, we see that they attempt to extend their investigations over the spiritual as well as the physical aspects of experience. It will be best to see from the instances of Boyle and Newton how a consideration of these attempts throws light on the roots of their work. Boyle was a devout man. He wrote much about his religious experience, and there is no doubt that personal piety and the missionary spirit were

[1] The best introduction to this subject is E. A. Burtt, *The Metaphysical Foundations of Modern Science* (1925).

among the chief things in his life. He deliberately tried to reconcile religion and science. 'The seeming contradictions betwixt solid divinity and true philosophy,' he wrote, 'will appear to be but few, as I think the real ones will be found to be none at all.'[1] His way of reconciling the two is not indeed ultimately satisfactory. He goes about it by a division of spheres of influence: 'If geometry, or revelation, or experience, assure us of divers things, of which we can know but that they are, and what they do, not, what they are, and how they act, we must neither refuse nor neglect the study of such truths.'[2] But he himself deserved the title which he gave to one of his books, *The Christian Virtuoso*, and he exerted a great influence on the religious experience of Englishmen by holding up to them the works of nature as objects of pious contemplation.

That these thoughts coloured his scientific work is easily seen, but historians have not always known how they influenced his practical life. In his works he touched on innumerable questions of technology. He was a member, from 1664, of the Company of the Mines Royal and of the Battery Company,[3] and he investigated the making of fresh-water out of sea-water on behalf of persons who hoped to carry it on as a business.[4] These facts are not mentioned by Professor Hessen, who, however, does not fail to point out that Boyle was for some years a member of

[1] *Works*, iii. 523. [2] Ibid., iv. 54. [3] Ibid. v. 328.
[4] See his *Letter to Beal* (1683).

the Court of the East India Company. We happen to have a letter of Boyle's in which he speaks as though his chief interest in the East India Company lay in its opportunities of propagating Christianity in the East.[1] Are we to dismiss this as an example of self-deception or of mixed motives? We need be in no doubt. Fortunately the published *Court Minutes of the East India Company* show what part Boyle took in its affairs. From 1668 to 1679 his name is mentioned only four times as taking any part at all, and on three of these four occasions the business related to chaplains. In the same way he was a member of the Council for Plantations; but it appears to have been only because he was president of the Corporation for the Propagation of the Gospel in Foreign Parts.[2]

When seventeenth-century writers profess religious motives, they are to be believed unless there is evidence to the contrary. This applies to Sir Isaac Newton. It may be admitted that Newton was not assiduous in his attendance at Trinity Chapel; but there is not the smallest reason for questioning his sincerity when he avowed to Bentley that in writing the *Principia* he 'had an eye upon such principles as might work with considering men, for the belief of a Deity'.[3] His own studies on religious subjects were not devotional, but intellectual. That, however,

[1] *Works*, i. 67.

[2] C. M. Andrews, *British Commissions, Committees and Councils of Trade and Plantations* (1908), p. 76.

[3] Letter of 10 December 1692, in *Opera*, iv (1782), 429.

brings them into closer contact with the rest of his work. It was from no mere uncritical acceptance of Christianity that he encouraged Bentley, in his Boyle lectures, to apply the Newtonian system to the refutation of atheism. Nor was it by a mere aberration that he encouraged John Craig, a Scotsman to whom Gilbert Burnet gave a canonry at Salisbury, to write his *Theologiae Christianae Principia Mathematica* (1699). That book, indeed, is on the whole absurd; but it is a sign that Newton was not satisfied with a mere division of spheres between theology and mathematics. There is more evidence to that effect in his writings on chronology and prophecy. When he studied the 'two notable corruptions' of the Scripture text in which trinitarian opinions had been interpolated (1 John v. 7; 1 Tim. iii. 16), he did nothing that was technically unorthodox; but liberal Christians have taken the treatise as showing that he was at least interested in unitarian doctrines.[1] That he was so is yet another proof that he was trying to work the different parts of his experience into a consistent whole: without the doctrine of the Trinity, theology appeared to many of his contemporaries, unitarians

[1] Mr. J. M. Keynes kindly informs me that unpublished Newton manuscripts make it clear that he held Arian opinions strongly and definitely, that he was consequently not in a position to subscribe to the Thirty-Nine Articles, and that this explains his refusal to take Orders and his failure to obtain academic preferment. The two corruptions studied in his posthumously published paper were well known before his time, and I do not know of any competent modern study which shows how far his discussion of them was original.

or deists, much easier to reconcile with scientific opinion. Taking Newton's writings together, then, we are justified in regarding his religious works not as irrelevant appendages, but as properly belonging, in his view, to the thematics of science.[1]

There is, indeed, a remarkable analogy between the most famous of his successes as a scientist and what appear to be his most futile inquiries in science and beyond it. Very early in life he discovered the principle of universal gravitation, which is still the supreme example of the simple explanation of a multiplicity of complex phenomena. When he moved on to other fields of thought he seems to have sought similar clues to other labyrinths. In his laboratory at Trinity he carried out chemical experiments, starting from the medieval legacy of alchemy and transmutation. Some of these might have had practical and even economic applications, and some of them did in fact lead on to an improved thermometric scale; but there is no doubt that their main purpose was to find a simple solution of the manifold forms of matter. In chemistry Newton achieved no more than minor and incidental successes. When, however, later in life he turned to an intense study of apocalyptic writings, he was still engaged in the same sort of attempt: the materials were different, but his search for a key to

[1] On p. 24, Professor Hessen refers to Newton's interest in the calendar, but without any allusion to the fact that the great reform of the calendar in the sixteenth century, like much of its earlier development, was ecclesiastical and not economic in its purpose.

the riddle of the universe was a continuation of his discovery of a key to astronomy and of his search for a key to chemistry. Thus his method itself led him on from science to theology.

There is one small point which should here be mentioned. Max Weber has drawn a distinction in this matter between Catholic and Protestant religion. He formulated a famous doctrine, with which we are not now concerned, about the influence of Protestantism on the spirit of capitalism. As an appendix to it he stated very briefly a complementary view about technology.

> 'Almost all the great scientific discoveries of the sixteenth and even the beginning of the seventeenth century were made against the background of Catholicism. . . . The Catholic Church has indeed occasionally obstructed scientific progress; but the ascetic sects of Protestantism have also been disposed to have nothing to do with science, except in a situation where material requirements of everyday life were involved. On the other hand it is its specific contribution to have placed science in the service of technology and economics.'[1]

It does not appear to me that this generalization is borne out by the facts. We have seen that Spain and Portugal were homes of the studies of navigation and medicine. In the sixteenth century Italy was the most fruitful field of science and technology;[2] in the early

[1] Loc. cit.

[2] The Italian superiority lasted in some ways longer than is often supposed. The English were indebted, in the building of the

seventeenth France and the Catholic Netherlands had some great names; in the late seventeenth and eighteenth England and Holland had their turn. But there was a great deal more besides religion to account for this: many other elements of economic history were tending to the same result.

In surveying the social background of the scientific movement, we have now distinguished five different groups of influences which worked upon science from the outside: those from economic life, from war, from medicine, from the arts, and from religion. What is left, then, of the independence of science? If we keep to the biographical method in which hitherto we have followed Professor Hessen, we shall find that there still remains a motive which we have not considered. 'Truth is the same thing to the understanding, as music to the ear, and beauty to the eye.'[1] The disinterested desire to know, the impulse of the mind to exercise itself methodically and without any practical purpose, is an independent and unique motive. We might examine it by tracing through the thought of the sixteenth and seventeenth centuries the distinction between pure and applied science; but

Tangier Mole, 1663–83, the largest engineering work till then undertaken by their nation, to the advice of Genoese engineers: E. M. G. Routh, *Tangier* (1912), pp. 349–50, 354. See also R. Hooke, *Diary* (1935), 11 February 1675/6–4 August 1679, for a number of entries on discussions between Hooke, Redding, Philips, and Shere about the Mole.

[1] J. Arbuthnot, 'Essay on the Usefulness of Mathematical Learning' (1701) in *Life and Works*, ed. G. A. Aitken (1892), p. 410.

the quickest and clearest way of disentangling it is to abandon the biographical point of view and take that of history. The biographical or psychological point of view is unsatisfactory because, in the first place, from it we see the scientist's thought from the outside: from this point of view there is no difference between true thought and false. Again, the biographical treatment of the history of thought is abstract. It isolates one aspect of the whole in the same way as a national history isolates one aspect of the history of mankind. To see the whole all round we must have more than these abstractions. The scientific movement was not the mere aggregate of the efforts of many individuals, each one of whom can be explained in terms of his social position. It was a common enterprise, partially incarnated in each of them, but having its own existence and nature, not to be explained except as a whole greater than its parts. History is always something other than a sum of biographies, and this is even more evident, though not more true, in the history of thought than elsewhere.

Newton's mind was in close communication with many minds, of various classes and countries and centuries; and the communication of two minds means not merely that they touch one another, but that the same thing is in them both, or rather that they are to that extent identical. Externally this intellectual community is embodied in the machinery of organized knowledge, in the press and libraries, above all in universities. The pursuit of knowledge

in universities is a self-perpetuating tradition. The study of mathematics, for instance, was an established part of their curriculum everywhere centuries before Newton's time. The mathematical progress of the sixteenth century strengthened it partly by mere emulation between different centres of learning. In the successive advances of mathematical teaching in England from the time of Wolsey to the time of Henry Lucas, whose chair Newton held, I believe this and nothing more utilitarian was the prime motive.[1] Newton, when he went to Cambridge as an

[1] Historians have sometimes inferred too much from the well-known autobiographical remarks of John Wallis in which he says of his young days '*Mathematicks* (at that time, with us) were scarce looked upon as *Academical* Studies, but rather *Mechanical*; as the business of *Traders*, *Merchants*, *Seamen*, *Carpenters*, *Surveyors of Lands*, or the like; and perhaps some *Almanack-makers* in London. . . . For the Study of *Mathematicks* was at that time more cultivated in *London* than in the Universities' (Appendix to the Preface to T. Hearne's edition of Peter Langtoft's *Chronicle*, 1725, p. cxlvii). Wallis went up to Emanuel in 1632, and wrote these reminiscences sixty-four years later. They may be compared with the title which William Bedwell gave in 1636 to his version of the geometrical lectures of Ramus: *Via Regia ad Geometriam; the Way to Geometry, being Necessary and Useful for Astronomers, Geographers, Land-Meters, Seamen, Engineers, Architecks, Paynters, Carvers*, &c. There was a public lecture on mathematics in London before 1588 (Stowe, *Survey*, ed. Kingsford, i. 75). According to Bedwell's preface part of Ramus's *Scholae Mathematicae* was translated more than thirty years before his time by Thomas Hood, who taught these arts in the Staplers' Chapel in Leadenhall. The chairs of astronomy and geometry in Gresham College were founded in 1597. They were held by eminent men; but it is clear from John Ward's *Lives of the Professors of Gresham College* (1740) that the college depended on Oxford and Cambridge to supply them.

undergraduate, stepped straight into this tradition; and when he had shown his powers he was enabled by a fellowship to devote himself entirely to mathematical and scientific studies. It was the social function of the universities thus to set free from the pressure of other motives men who had the desire to know. The changing social and economic conditions of Newton's time did something to increase this social provision, especially for mathematics and science; but the universities and their studies had their own laws of growth. At their heart was the disinterested love of truth. This we must add as a sixth, and greatest, to the five motives which we have distinguished as actuating the scientific movement. The others helped to clear the way for it; they could not and did not create it.

By these six interpenetrating but independent impulses, the scientific movement was set going; and some of its results percolated down into practice and were applied. On the other hand, the greater part of the scientific labour then done brought no practical return until long afterwards; the growth of science, limited by the laws of its own coherence and that of the universe, touched the needs of human life only here and there. We have conceded that the principles worked out by Newton and his contemporaries were those which were required for the solution of certain problems of transport, mining, and metallurgy. But the significance of that admission may easily be misunderstood. It is true as far as it goes; but there are

two qualifications. First, there were other equally pressing economic problems to the solution of which the scientific movement did not contribute. Boyle foresaw that chemistry, geology, botany, genetics ought to be able to transform agricultural methods;[1] but for more than a century after his time they were still only groping towards the cardinal discoveries which enabled them to do so. 'We may be tempted to ask', he also wrote, 'what handy work it is, that mechanical contrivances may not enable men to perform by engines';[2] but, far as we have gone on that road, we have still far to go. Secondly, there were long and valuable scientific investigations from which no practical application was foreseen at all. Electricity and magnetism, except in so far as they were related to the mariner's compass, were studied by something nearly approaching to absolutely disinterested inquiry. Long after Newton's time the study reached a point where it broke through to truths which could be applied in the making of light and power and heat. Like these, many others of the greatest practical results were attained not by seeking for them for their own sakes, but as the unsought reward of those whose conscious aim was systematic knowledge of reality. More than one of the scientists of that age used the old fable of the man who dug for hidden treasure and failed to find it, but by the digging made his own garden more fruitful. Fantastic aims have sometimes led to valuable dis-

[1] *Works*, iii. 144–5. [2] Ibid. iii. 173.

coveries, and utilitarian aims are sometimes better justified by failure than by success. There are limits to the control which capitalists and governments can exercise over the development of science. They can pay for it and equip it; in a sense they can direct it; but only the scientists can know what investigations it is best to make and in what order. Unless they set their own problems, they cannot make their own peculiar contribution to solving those of industry, transport, and commerce. A friend to whom he had lent a copy of Euclid's *Elements* asked Newton of what 'use or benefit in life' the study of the book could be. That was the only occasion on which it is recorded that Newton laughed.[1]

[1] Brewster, ii. 91–2.

*Additional Note to p. 74 above.* The story about David Gregory appears even more improbable in the light of a note by his son and namesake the Savilian professor, which deals with a suggestion by Newton himself for remedying a defect in artillery (*David Gregory, Issac Newton and their Circle*, ed. W. G. Hiscock (1937), p. 25).

## IV

# SOCIAL CONTROL OF TECHNOLOGICAL IMPROVEMENT

EVER since men and women first worked with their hands, they have admired dexterity, and from the very remote past they have believed without reflection, or as we say 'instinctively', that invention, which is a higher sort of dexterity, must be useful. From time to time thinkers who try to take a systematic view of human affairs take hold of this instinctive belief and work it into their systems. We have seen that some of the founders of modern science did this; their contemporaries who were outside the circle of scientific thought had equal confidence in the value of technological improvement. There were men who, though not quite scientists, were enthusiasts for education and organized discovery, like John Amos Comenius and Samuel Hartlib. These belonged to a class of which the greatest was Bacon, and they were all carried forward by a great wave of adventurous hopefulness which we may trace back to the fifteenth century. The age believed in action; the world was its oyster. Pistol set out to open it with his sword, but there was active thought too, and there were many who plied their mathematical instruments with the same aggressive energy.

It does not, then, require any special explanation if we find confidence in invention as one of the ingre-

dients in the economic thought of the period. Sometimes, indeed, there are threads which connect it with the scientific movement. John Locke, for instance, stood nearer to the scientists than any other of the leading economic thinkers, and it was no doubt partly for this reason that he repeatedly drew attention to the 'large field for knowledge' in labour-saving and economic inventions. He rightly ascribed to them a great part in the progress from barbarism to civilization.[1] Those pamphleteers who agreed with Locke in their chief economic opinions strongly agreed with him, from their more limited points of view, in this.[2] But we must not suppose that this was merely a result of their contact with Locke, or of Locke's contact with the scientific movement. Locke might have come to the same conclusion by an entirely different road. His social ideas were sharply opposed to those of the radicals who had their brief and dangerous opportunity in the time of the Civil War and the Interregnum. In comparison with them he was a conservative; but very similar views about invention are coupled with his reassertion of the rights of property and with their criticism of the established order.

[1] *Human Understanding*, bk. iv, ch. xii, § 12; Lord King, *Life of Locke* (1829), p. 88; see also J. Bonar, *Philosophy and Political Economy* (1893), p. 93.

[2] J. Cary, *Essay on Trade* (1695), pp. 145–7; J. Bellers, *Essay for Imploying the Poor to Profit* (1723), p. 8. In his *Essay towards the Improvement of Physick* (1714), pp. 17–18, Bellers proposes the endowment of the Royal Society, amongst other purposes, for an annual prize 'to every Mechanick that shall produce the best Piece of Work, or any Thing new'.

Their hope of a better world was another expression of the great hopefulness of their age. Gerard Winstanley, the leader of the English 'Diggers', believed in technical improvement as warmly as any scientist. When Locke was twenty Winstanley wrote: 'Let no young wit be crushed in his invention', and again: 'Let every one who finds out an invention have a deserved honour given him.'[1]

From this side and from that, then, the belief in 'improvement' flowed in on the economic writers. It was in the air, and it was in the air of economic life as well as of science and social agitation. Every active country had its makers of real or imaginary inventions; every minister was besieged by the 'projectors' or *arbitristas*, who, for a consideration, were ready to reveal new ways to win wealth. There was no sharp distinction between the fantastic failures, like the Marquess of Worcester, and the brilliant successes, like Robert Hooke. Sir William Petty had one foot on either side of the line, and there were many like him. In his admirable study of the economic thought and policy of the period, Professor Heckscher has brought together evidence to show that the theoretical attitude of mercantilism was not opposed to technical inventions, and he identifies as the fundamental reason for this 'the spirit of progress, the lust for

[1] *The Law of Freedom* (1652), p. 71. Winstanley had no economic doctrine of the value of invention and the obstacles to it; he merely held that 'fear of want and care to pay Rent to Task-masters hath hindered many rare Inventions', and so 'Kingly Power hath crushed the Spirit of Knowledge'.

enterprise and adventure', the love of novelty for its own sake.[1]

A good, if indirect, illustration of this instinctive attitude of the time to technical improvement is to be found in a famous passage of *Gulliver's Travels*. Jonathan Swift, though he accepted the doctrines of Locke on some other matters, had a low opinion both of scientists and of projectors. He jeered at the great Robert Boyle in his 'Meditations upon a Broomstick', and he jeered at them all in the Grand Academy of Lagado. Yet he could write that tremendous chapter in which Gulliver explained the institutions of Europe to the king of Brobdingnag. After commanding Gulliver, as he valued his life, never again to mention the secret of gunpowder, the king expressed his contempt for statecraft,

> 'and he gave it for his opinion, that whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together.'

Swift drives it home with his overwhelming scorn; but it is part of the common intellectual property of his time and ours. To enrich the world by greater production is positively good, and in comparison with that we easily think the worse of the scientists

[1] *Mercantilism* (1935) ii. 126 ff. The best account of this spirit is in Professor Werner Sombart's *Moderne Kapitalismus*, especially bk. ii, Abschnitt iii, 'Die Technik'.

who invented gunpowder and the statesmen who use it. These, however, are first thoughts, and close behind them lie others which do not easily square with them. To raise a greater crop on a small plot of ground cannot be of much concern to mankind or even to our country; for these high interests improvement on the great scale is needed; but how can there be such improvement unless the statesman does his share? The agricultural botanist must be educated and rewarded and, if need be, protected against his enemies; his invention must be made available by industry and transport. Here is work for the whole race of politicians. At any time and under any conditions, the work of government and social organization is necessary if the work of science is to be effective. In Swift's time, as we shall see, technological progress raised thorny problems of social control, and the statesmen had the responsibility of dealing with them. His easy refuge from the hard realities of social life was fallacious. The politician and the producer were both needed, and when two people each make an essential contribution to a joint product, it cannot be true that one does 'more essential service' than the other.

The roots of the social strife about inventions lie as deep as the belief in their value, for over against that belief there lies in the unreflective strata of our convictions a conservatism which makes us dislike them. Economic inventions often provoked resistance. There were indeed some which pleased every

one by creating employment and raising the standard of life: Boyle had this to say in praise of the new methods in making clocks and watches and instruments of precision. These, however, were exceptions. Most of the inventions, whether scientific or not, abridged human labour, were, as we say, 'labour-saving' devices; and 'labour-saving' is another word for reducing employment. Technological unemployment is a much older thing than either of the words that compose its name.[1] It was a thing that hit the individual craftsman directly, and to which he opposed a simple, instinctive resistance. There are many records of machine-breaking in this period, from many countries. In England, for instance, the first saw-mills had to stop working in 1663 because of popular opposition, and the same thing happened again at Limehouse as late as 1767.[2] There were disturbances against the ribbon-loom in 1676.[3] There was smashing of stocking-frames in 1710.[4] In 1726

[1] For contemporary opinion on unemployment generally see T. E. Gregory, 'The Economics of Unemployment in England, 1660–1713' in *Economica* (1921), reprinted in *Gold, Unemployment, and Capitalism* (1933), and E. Furniss, *The Position of the Laborer in a System of Nationalism* (1920).

[2] A. Anderson, *Origin of Commerce*, ii (1764) 354. This, in contrast with the extensive use of saw-mills in Holland, is used as a reproach against the English in the *Considerations on the East India Trade* (1701), and by Bellers, loc. cit.

[3] Hale, *Pleas of the Crown*, i (1736) 143* ff. For the ribbon-loom generally see G. Unwin and A. P. Wadsworth in A. P. Wadsworth and Julia de L. Mann, *The Cotton-Trade and Industrial Lancashire* (1931), pp. 98 ff.

[4] See J. Blackner, *History of Nottingham*, 1815.

—we do not know for what provocation—frame-breaking was made a capital offence.[1] The great textile inventions of the eighteenth century were followed step by step by wrecking, from the sacking of Kay's house at Bury in 1753 to the Luddite riots of 1811–12. The sabotage was not always due to unemployment; sometimes it was a protest merely against low wages and high food prices; but from one cause and another it was characteristic of the periods of early capitalism and the Industrial Revolution. Almost its last open demonstration came when the threshing-machines were destroyed in 1830. After that it lingered on obscurely, but the organized labour movement showed a more powerful, as well as a saner, way of working for the same ends.

How far did the fear of unemployment in the earlier period find expression not merely in this instinctive reaction but in the policy of constituted economic and political organizations? It is commonly said that it influenced the guilds and corporations. The Dutch economist, Pieter de la Court, who considered these bodies hurtful, was translated as saying that their monopolies made them slow, inactive, and 'less inquisitive'.[2] Sprat, in his *History of the Royal Society*, when he is writing about inventions, says:

'The main difficulty . . . arises from the suspicions of

[1] 12 Geo. I, c. 34.

[2] *The True Interest and Political Maxims of Holland* ascribed to John de Witt (1743), pp. 60–1. The original, for which see below, p. 115, says merely *dom en traag*, that is, stupid and sluggish.

the tradesmen themselves: they are generally infected with the narrowness that is natural to corporations, which are wont to resist all new comers, as professed enemies to their privileges; and by these interessed men it may be objected that the growth of new inventions and new artificers will infallibly reduce all the old to poverty and decay.'[1]

Neither of these writers gives any instances, and from the nature of the case we must not expect to find many striking instances of the suppression or discouragement of innovation. It has been said that decadence does not lend itself to documentary illustration,[2] and the same is true of conservatism, for conservatism works by stationary dead-weight more often than by overt acts. Nevertheless, there are examples of guild action against new tools, machines and processes. In the most important of these the guilds did not rely on their own authority, but called in the aid of the state. It was presumably in consequence of appeals from the organized crafts that parliament in 1552 prohibited the use of gig-mills, machines for picking out knots in the weft of cloth.[3] In 1623–4 Charles I by proclamation ordered the destruction of an engine which had lately been used in making needles, together with the needles so made.[4] Nine years later, when he likewise prohibited the casting of brass buckles, he gave

[1] p. 398.

[2] A. F. Leach, *Educational Charters* (1911), p. li.

[3] 5 & 6 Edw. VI, c. 22.

[4] R. Steele and Earl of Crawford, *Tudor and Stuart Proclamations* (1910), no. 1368.

as his reason the complaint of the Company of Buckle-Forgers, Filers, and Trimmers (members of the Girdlers' Company). He cited a report of the lord mayor and aldermen to the effect that cast brass buckles were brittle and that they were made by only four or six persons in London, whereas there were 300 whose sole livelihood was from making iron buckles and harness, and a brass-caster could make more buckles in a day than ten forgers could. The prohibition was thus avowedly to prevent unemployment.[1] It was most likely these acts of the reactionary paternalism of Charles I, if it was any overt acts, which prompted some characteristic remarks of Thomas Fuller. He reflects upon the dog-drawn plough that he saw in Hampshire:

'I have heard that some politicians are back friends (how justly I know not) to such projects, which (if accomplished) invite the land to a losse, the fewer poor being thereby set awork; that being the best way of tillage which imployeth most about it, to keep them from stealing and starving: so that it would not be beneficiall to state, might a plough be drawn by butterflies, as which would draw the greater burden on the common-wealth, to devise other wayes for the maintenance of the poor.'[2]

[1] R. Steele and Earl of Crawford, *Tudor and Stuart Proclamations* (1910), no. 1653. The protection of the French cord-and-button makers' guild (1694–1700), and its English parallel are comparable. Heckscher, i. 171, 265, n. 49.

[2] *Worthies*, Hampshire. A curious incident in which the old feeling against monopolies made its appearance was the excommunication of the economist and business man Richard Haines in 1670 by the Baptist minister Matthew Caffyn, for obtaining a patent for

Statesmen, indeed, who thought about public order and the burden of poor-rates, did not need the promptings of the guilds. In 1662/3 Sir Robert Moray and Mr. Hoskyns related to the Royal Society the way of making briquettes or 'burning-balls' at Liége, 'which is a thrifty kind of fewel, lasting long, and burning without smoke, and leaving no ashes'; but Sir Paul Neile, mindful of the coastwise coal-trade from the Tyne, suggested that the practice of this thriftiness would prove prejudicial to shipping.[1] This point is made again in a hilarious skit which John Arbuthnot published in 1716, *The Humble Petition of the Colliers, Cooks, Cook-Maids, Blacksmiths, Jack-makers, Braziers and Others*, against the plan of the virtuosi to introduce cooking by burning-glasses instead of coal.[2]

The state might even have a direct interest in stopping an improvement if it would lead to the substitution of an article manufactured at home for one previously imported from abroad on which customs had been paid. On various occasions the customs commissioners reported on the claims of inventors that their inventions would benefit the revenue.[3] The plainest instances of obstruction on the ground that they would have the reverse effect relate to new methods

a process for cleaning the seed of nonsuch trefoil or hop clover. For the story and references to the pamphlets concerning it see C. R. Haines, *Complete Memoir of Richard Haines* (1899).

[1] T. Birch, *History of the Royal Society*, i. 177.

[2] In *Life and Works*, ed. G. A. Aitken (1892), pp. 375–8.

[3] *Calendar of Treasury Books*, 1685–9, pp. 602, 670.

of salt-boiling, especially in the reign of Queen Anne.[1] By that time, however, the restrictive paternalism of the state and the obstructive power of the guilds were both losing their force. Two incidents will show how this affected technological progress. In 1696 the Exeter Company of Weavers, Fullers, and Shearmen petitioned the commons to prohibit the use of the skey in stretching serges. It was already in use in every part of England except the south-west, and also in Ireland and Holland. The efficiency of an export industry and its power to produce as cheaply as foreign competitors were paramount arguments for parliament then, and the Company petitioned in vain.[2] Five years after that the Company of Gold and Silver Wire-Drawers in London was trying to get one of its members to submit to its rule. He seems to have had machinery of which the secret was not known to his fellows, and he made it a condition of submitting that such of its officers as used engines should be kept out of his work-rooms.[3] The guild had no power to stop the introduction of the machine, and there is no evidence that it desired to do so; but if its supervision

[1] E. Hughes, *Studies in Administration and Finance* (1934), pp. 427–8.

[2] *Commons' Journals*, xi. 459, 487, 494, cited by W. G. Hoskins, *Industry, Trade, and People in Exeter* (1935), p. 50. For the word 'skey' see *Oxford English Dictionary*, where, although this sense is not given, the word, derived from the Dutch *schei*, tie-piece, may, as Dr. C. T. Onions kindly informs me, be presumed to be the same. I assume that Mr. Hoskins is right in ascribing the petition to the Company, which, however, is not named in the *Journals*.

[3] H. Stewart, *History of the Worshipful Company of Gold and Silver Wyre-Drawers* (1891), p. 87.

endangered his secret, the member would withdraw. Guilds which had so little real authority could no longer impede innovation, and in England guild action was not an important check on innovating individuals after the middle of the seventeenth century.

The old system of regulation was dying, and the new capitalist industries were growing strong. Are we to suppose that, while the old guilds and the old paternalism shut out the refreshing breeze of invention, the capitalist adventurers opened their windows to it wide? It would be wrong to answer that question with a simple affirmative, and the true answer must distinguish different kinds of capitalists, and different stages in the process. So far as England is concerned, the first stage was, as we have already seen, that of the rapid economic expansion under Queen Elizabeth, when, on the rising tide of the American silver, new and expensive processes were introduced by capitalists. In his masterly sketch of this period the late George Unwin asked why so little was heard of the widespread economic activity in the annals of the time, and why the Industrial Revolution did not happen a century earlier. 'The answer to both questions is the same', he went on. 'The triumph of honest enterprise was overshadowed by the feverish delusions of speculation and the selfish greed of monopoly.'[1] The capitalists who brought in the new industries normally, almost invariably, asked for pro-

[1] *Studies in Economic History* (1927), p. 324, reprinted from *Shakespeare's England* (1916).

tection, and the form which it took in those days was that of patents of monopoly. Most of us nowadays do not regard monopoly as such with the austere disfavour which was common a generation ago, and to which Unwin, among historians, gave the most powerful expression. We are familiar with the idea that monopoly, the elimination of competition within an industry, may enable it to organize itself, to reduce costs, to compete against foreigners. We describe universal monopoly as planned economy. The many monopolies granted during Queen Elizabeth's reign and under her successor down to about the year 1610, although they covered the whole country, did not at any time wear the appearance of a national plan. They caused indeed a national resistance, and in three successive crises the elected representatives of the nation put an end to this method of fostering infant industries.

The grant of a monopoly to a projector was in theory a transaction to which there were three parties, all of whom were to profit from it.[1] The nation, the body of consumers, was to have the benefit of the new industry—alum, salt-boiling, glass-blowing, soap-making, or what not. It might, as in the instance of

[1] For the subject in general see W. H. Price, *The English Patents of Monopoly* (1906); Sir W. S. Holdsworth, *History of English Law*, 2nd ed., iv (1924), pp. 345–54, vi (1924), 330 ff. It is dealt with in all the general works on the economic and constitutional history of the period, and there is a good selection of documents on the Elizabethan crisis in R. H. Tawney and Eileen Power, *Tudor Economic Documents* (1924), ii.

saltpetre, be not merely an economic benefit, but the national advantage of developing an important war industry at home. The projector was to have his profits, except for some part of them which the Crown, the third party, bargained for as its price. This system was easily abused, and the first abuses which became notorious arose when the needy Crown granted similar monopolies to courtiers or capitalists who offered a similar price for the control of industries which were not new or even of economic functions like insurance. When the prices were high, the projectors incompetent, and the established practitioners capable, both these and the consumer had a grievance. In 1601, in the first of the three crises, parliament stormed against these grievances, and Queen Elizabeth, who had the gift of making common sense dramatic, won great credit by yielding. She withdrew some of the monopolies, and promised that the courts of law should decide in all cases where the remaining monopolists were accused of unduly stretching their privileges.[1] This did not prevent a second crisis in the time of James I, when the main lines of the patent law as we now know it were laid down, nor a third when the Long Parliament cleared up some abuses which had recurred under the personal government of Charles.

[1] The failure of Lee to obtain a patent in England for his invention of the stocking-frame, which he took to France, may be due to the Elizabethan government's fear of creating unemployment; but there is no direct evidence on the point: see F. A. Wells, *The British Hosiery Trade* (1935), pp. 25–6.

Innumerable questions of law were raised in these discussions and many minor economic questions; but the main economic discontents arose from the fact that whenever the absence of foreign competition enabled them to do so the projectors all used their monopolies to raise their prices. Many of them, however, were exposed to foreign competition, and in every instance except that of glass-making, the monopolies gave them not the sole right of selling their product in the kingdom, but merely the sole right of making it. They had not, therefore, the facilities which a protective tariff would have given them for absorbing their competitors and enabling them to share in the benefit of enhanced prices: all they could do was to use the law to extinguish domestic competition. Since some of them were not industrial managers but pure financiers, and others mere swindlers, they might easily have destroyed the industries they professed to promote. Parliament, in opposing them, was on the side of industrial expansion and improvement. How little they really did for that cause may be illustrated in two ways. Some of them, when they obtained a privilege for manufacture, found that it paid them better to neglect the manufacture and, by buying up the products of others whose continued manufacturing activities they tolerated, to make the easier profits of trading. This was done at the end of the seventeenth century, for instance, by the new Corporation for the Linen Manufacture in England. The other illustration of the lack

of enterprise among the monopolists is simpler. It is the difficulty of finding an instance of a monopolist who, after procuring a patent for one improvement, subsequently introduced another in the same manufacture.

The two main principles of the patent law as it emerged from the three crises of the seventeenth century defined the exceptional cases in which industrial and commercial monopoly might still be granted. First, if a genuinely new process were invented or introduced from abroad, a patent of monopoly might be granted for a limited term of years.[1] This is the principle, familiar to all of us, in virtue of which the inventor is to have his reward. From the late eighteenth century, if not before, continental writers sometimes maintained that by this means the English gave invention an effective encouragement which it did not receive elsewhere. It would be difficult to test this opinion by comparison with the facts, but there

[1] The application of this principle has brought into existence a number of most useful works of reference. The first specification was enrolled in 1711: there are nearly 100 volumes of *Abstracts of Specifications*, grouped by subject matter, to which the Index Society published an Index in 1879, as Appendix 2 to the *Report* of its Second Annual Meeting. Bennet Woodcroft prepared for the Commissioners of Patents from 1854 onwards a number of very useful indexes arranged chronologically, by subjects and by persons. R. B. Prosser, alone and in collaboration with others, made a series of local lists of inventions covering all the English counties except London and Middlesex: some of these are unpublished, some privately printed. E. W. Hulme, *Early History of English Patent System* (1909), gives a list of grants of privileges, 1554–1603. For the law see also D. Seaborne Davies in *Law Quarterly Review*, l.

are so many notorious instances of inventors who were cheated of their reward, and the working of the patent laws was so unsatisfactory, that it must be regarded as doubtful. If we are to seek in English law, as distinct from economic and intellectual conditions, elements favourable to invention, they ought to be sought first, so far as the eighteenth century is concerned, in the breakdown of monopolies, and the width of the industrial field where there was freedom to employ new methods without supervision. It was this freedom, as historians have always recognized, which enabled Lancashire and Birmingham to take advantage of their great opportunities in expanding markets.

The second main principle of the law as it was settled in the seventeenth century was that monopolies might still be granted to chartered companies. Very likely this exception was originally due to the fact that the great trading companies were the most powerful economic organizations of the time, and had much influence in parliament; but it was justified on the plausible, or perhaps even sufficient, ground that for their large and costly undertakings special protection was needed. In practice, however, they too used monopoly as a shield for stagnant routine. The medieval guilds and the Merchant Adventurers are often reproached for 'limiting output', but the great capitalistic companies of the new era, one after another, having expanded up to a certain point, rested there and aimed at keeping up their prices. The

classical example is that of the Dutch East India Company which, as early as 1625, began to root up 'redundant' clove bushes. Sir William Temple has an interesting remark on another side of the company's policy, and on this point his authority, even if uncorroborated, seems good. He complained that the scientific results of exploration had been poor because it had been carried on only for commercial reasons, and wrote that he had heard it said among the Dutch that their East India Company had long since forbidden, under the greatest penalties, any further attempts to discover the 'austral continent', having already more trade in those parts than they could turn to account, and fearing that some more populous nation of Europe might make great establishments of trade in some of those unknown regions, which might ruin or impair what they already had in the Indies.[1]

The main principles of the English patent law were established before the middle of the seventeenth century, that is before the great turning point marked by the downward movement of prices. That movement brought with it the new device of economic policy for which many political and other changes had prepared the way, industrial protectionism. Governments had become stronger; with improvements of transport, education, and finance, they were increasingly able to put into practice the idea of managing

[1] 'On Ancient and Modern Learning', 1690, in *Critical Essays of the Seventeenth Century*, ed. Spingarn, iii. 59.

each country, especially in its trading relations with other countries, as one great unit. They therefore imposed a multitude of new restrictions on industry, which pressed on technological change as hardly as on any other kind of enterprise. The most famous of them were the prohibitions enforced in France and England against Indian cottons. These not only held off the most dangerous competitor of the European textile industries until the Industrial Revolution enabled England to meet it on its own ground and beat it in its home market, they also stifled the better Indian methods when they had been transplanted to Europe. It is difficult to believe all the stories that are told of this struggle, especially the estimate that in France, partly through executions and partly through armed affrays, it cost the lives of some 16,000 people; but these stories are symbolic of the fact that it was the decisive battle of European against Asiatic industry, and to secure its victory Europe blotted out all the elements among its own population who might have profited from or imitated the Indian methods. The calico-printing industry, which began in England, France, and the Netherlands about 1670, was extinguished in France by 1686, in England by 1721 (though it was allowed to begin again in England partially in 1736 and freely in 1774).[1] These prohibitions were made in the interests of the great exporting industries, not in consequence of guild agitation, but by governments which regarded the nation's foreign

[1] For references see Heckscher, i. 172–5.

trade as a national interest. It would perhaps be unjustifiable to say that the spread of capitalism increased the power of the industries to put pressure on the governments; but it is clear that it did not diminish their readiness to do so.

Such was the experience of the industrial countries of Europe from the half-abortive industrial revolution of Elizabeth's time to the half-abortive industrial revolution which began in Charles II's time. The new industrial organization, like the old, constantly tended to monopoly; the new forms of monopoly, like the old, constantly tended to stifle enterprise. The economic writers who looked back on this experience in the late seventeenth century and the early eighteenth were caught in a series of dilemmas. There was not among them a single one who attempted, like a modern economist, an impartial survey of all the factors of economic life; but as they argued against one another, they were compelled to become less crudely partisans of particular interests, and to take more and more areas of fact into their observation. The more they did this, the more sharply their dilemmas were formulated. A writer who skated over them without coming to the point was Sprat, the historian of the Royal Society. He was not indeed the advocate of any business interest, but he spoke for technological improvement itself. We have seen that he condemned the conservatism of the guilds. He held that it is manufactures that make a country rich. 'The hands of men employed are true Riches:

the saving of those hands by inventions of *Art*, and applying of them to other *Works*, will increase those *Riches*.' He would not admit that this applying of them to other works might be difficult to compass. 'If there be not vent for their productions at home, we shall have it abroad.' The addition of labourers raises prices, but high prices are a sign of prosperity, cheapness of the scarcity of money and people.[1] The Dutch, unlike the English, wisely welcomed all inventions and immigrants.[2] Technical progress was not to blame for 'the want of employment for younger Brothers, and many other conditions of men; and . . . the number of our poor, whom *Idleness*, and not *Infirmities* do impoverish'.[3] But this is mere assertion, a mere appeal to faith. Sprat does not tell us how high prices are to benefit the labourer, or how one man's employment benefits another man who is unemployed. He does not recognize that technological unemployment raises a problem which the economist must examine.

Another writer who sometimes recognized it, but could not solve it, was Daniel Defoe. Defoe's instincts were all on the side of invention. He made Robinson Crusoe triumph over his adversities by

[1] *History of the Royal Society*, p. 400.

[2] p. 401. Contrast the opinion of de la Court above, p. 98. Onslow Burrish, afterwards solicitor to the board of trade, in his *Batavia Illustrata* (1742), p. 374, ascribes the failure of the Leyden manfacturers to adopt English methods of shear-making to their aversion to novelty and the natural perverseness of their temper.

[3] p. 422.

applying reason to the mechanical arts, and he made Crusoe lecture his readers on that theme.[1] It would be frivolous to stress the technological language of Crusoe's tribute to his dead wife: 'She was, in a few words, the stay of all my affairs, the centre of all my enterprises, the engine that by her prudence reduced me to that happy compass I was in.'[2] Sometimes in his economic works, Defoe was on the same side. He laughed at the Russian prince who was said to have ordered out of his country an Englishman who had tried to introduce a new kind of river-craft, to be sailed by eighteen or twenty men instead of 120, a scheme, as the prince thought, for starving his people. But in another passage of the same book, Defoe, as Professor Heckscher has pointed out, thought like the prince. He wrote:

'Notwithstanding in general, it is the Advantage of Commerce, to have all Things done as cheap as possible; yet . . . as it is the grand Support of Wealth and Trade in England, to have our Product consum'd, and in order to it, to have our People and Cattle employ'd; So it is not always the Advantage of England to lessen the Labour of the said People and Cattle by the Encrease of River Navigation.'[3]

Sometimes he went even further:

'All methods to bring our Trade to be managed by

[1] Shortly before the beginning of the excerpts from his Journal, and on 22 April 1660.

[2] In the *Farther Adventures*, published like the original book in 1719.

[3] *Plan of English Commerce* (1728), pp. 56–9, 227.

fewer hands than it was before, are in themselves pernicious to England. . . . 'Tis the excellence of our English manufacture that it is so planned to go through as many hands as possible; he that contrives to have it go through fewer ought at the same time to provide work for the rest.'[1]

That is as much as to say that there must be no labour-saving devices, and yet Defoe was a defender of the French commercial treaty of 1713, which, if parliament had accepted it, would have exposed English manufacture, 'so planned', to fresh foreign competition. It is not surprising that his inconsistency was exceptional. The more systematic writers, if they were not content with the existing state of things, might have sought for an increase of national wealth from a maintenance of protectionism coupled with a strong policy of efficiency and welfare. That is the ideal to which the statesmen of Europe nowadays pay lip-service; but at the end of the seventeenth century it was impossible. However much the belief in improvement may logically have prepared the way for it, other developments in thought and practice had counteracted its effect. Paternalism had been discredited by the Stuart tyranny. Parliament had

[1] *Giving Alms no Charity* (1704) in *Writings of the Author of the True-born Englishman*, ii. 439. This is what John Bellers wanted to do. In the pamphlet of 1723 cited above, p. 93, he says that 'Laws against the shortening of Labour are as unreasonable as to make a Law that every labouring Man should tye one Hand behind him, that two Men might be imploy'd in one Body's Work.' His own alternative was a scheme of philanthropic home-colonization, which was intended to be profitable, but was never tried.

almost ceased to legislate about the wages and conditions of labour or the standards of production. Monopoly, whether local or national, whether associative or capitalistic, had proved itself incapable of creative expansion. The prevalent religion and philosophy had convinced the new generation that the world ran best if individuals were left to take their chance by competing under the oversight of a Providence which had no terrestrial deputies. The writers on the side of protectionism and regulation were therefore the upholders of the existing system; the pursuit of intellectual consistency led to the system of natural liberty.

'Natural liberty' is a phrase which we associate with its use by Adam Smith; but it was used long before his time. It occurs in a book of which he possessed a copy, the English translation of the Dutch author from whom I have quoted a criticism of the conservatism of the guilds.[1] His criticism was

[1] *The True Interest and Political Maxims of the Republic of Holland* (ascribed to John de Witt, actually by Pieter de la Court) (1702), p. 70. See J. Bonar, *Catalogue of the Library of Adam Smith*, 2nd ed. (1932), p. 197, where a copy of the edition of 1743 is entered. There was a third English edition in 1746. In or about 1708 a pamphlet of four folio pages was circulated to members of parliament during the proceedings relating to the African Company, giving *Extracts of Divers Passages relating to Exclusive Joint-Stock Companies, taken from Monsieur de Witt's Treatise . . . translated in the year 1702.* It gives the passage about natural liberty on the first page. The first Dutch edition was of 1662, and the first English translation of 1702. Mr. Max Beer has kindly drawn my attention to the following sentence in Misselden's *Circle of Commerce* (1623), p. 112: 'Trade has in it such a kind of natural liberty in the course and use

directed not only against the guilds but against the great trading companies as well, and in this it was like the cutting argument of the famous English tract of 1701, the *Considerations on the East India Trade*. The anonymous author of that work came down on the side of universal cheapness, and repeatedly he supports his choice by urging the cause of technological improvement.[1] Standardization of the parts of ships, and the use of machinery as it was practised in Holland, cheap labour, 'new Imployments for the People', are what he advocates. He is against the most popular of the protectionist prohibitions. In a famous and eloquent passage he says that 'every individual Man in England, might be imploy'd to some profit, to do some work which cannot be done without him; at least, the contrary is not evident, as long as *England* is not built, beautify'd, and improv'd to the utmost Perfection, as long as any Country possesses any thing which *England* wants'. The words are strangely like some which have been used in our day to denounce the failures of natural liberty, and that makes it the more evident that the early advocates of natural liberty were not preachers of mere indifferentism. It was they who for the moment had

thereof, as it will not endure to be forced by any.' The words 'natural liberty' are, however, here used in a different sense from Adam Smith's, and there is nothing to connect this passage with him.

[1] See especially pp. 580–7, 595, 615, 620–9 in the reprint in J. R. McCulloch's *Select Collection of Early English Tracts on Commerce* (1856).

the right to claim that they were the friends of expansion, of invention, and of all improvements. Where the seventeenth-century scientific movement left off they, and the eighteenth-century capitalists whose energy they helped to liberate, went forward to the successes and the disasters of the Industrial Revolution.

## V

## SOCIAL SCIENCE

THE economic writers noticed in the preceding chapter showed few traces of the scientific spirit. They, and their contemporaries who wrote about similar subjects, were not patient, thorough, and impartial like the scientists, yet in various ways the manner and even the methods of science cast a reflection in what was written about economics and other social questions. Various writers began to hope that they might discover social truths by the same processes which were laying bare so many hidden physical truths. In every period the active and progressive branches of thought are bound to exercise this influence outside their own borders. As theology provided medieval thought with its framework and its language; as biology dominated the thought of the later nineteenth century; so physical science left its impress on seventeenth-century thought. It could not, indeed, simply be extended without alteration to cover social facts. These offered no opportunity for experiment, nor for observation with instruments. Social science, when it came, had to be different in these and other ways from natural science, and no one yet used the name 'social science' in any language; but the thing was coming into existence.

A number of English and continental writers laid it down that politics was a science. In the year of the

foundation of the Royal Society, for instance, Saint-Évremond, a Frenchman living in London, wrote a letter in which he included it among the sciences which particularly deserved the attention of gentlemen.[1] The others were ethics and polite learning, so that what he had in mind was not science in the narrower sense; but other authors applied the idea more strictly. About the same time economists and political writers began to use phrases which had originally expressed mechanical notions. The metaphor of the balance of trade was probably derived from the balance in book-keeping; but in the late seventeenth century it was used along with several similar expressions connected in people's minds with another kind of balance, equilibrium as the physicists studied it. There was the balance of property, a balance of parties,[2] the balance of power. It is even said, though I have not seen any proof of it, that the mere use of the word 'powers', to describe states in their mutual relations, springs from this habit of thought. It was not a mere matter of language. There were writers who hoped that the new knowledge would be extended systematically over the whole universe, and they did not ignore the life of men in

[1] *Letters of Saint Évremond*, ed. Hayward (1930), pp. 35–6. This is earlier than the other and more significant passages which I have cited in *The Seventeenth Century* (1929), p. 216.

[2] This phrase corresponds to the practical aims of King William III in the earlier part of his reign, and is used by Defoe in his *Appeal to Honour and Justice* (1715), near the beginning. For the other phrases see *The Seventeenth Century*, p. 214.

societies. Bacon included it equally with physical nature in his great programme for the future of learning. In this, as in many other respects, he did not foresee the exact course which the future was to take; but he was right in thinking that thought about man would advance in some sort of connexion with thought about nature.

In the century which began with Bacon and ended with Newton, the most tangible product of this connexion was the rise of statistics, the quantitative study of social facts. It is well known that modern statistical studies trace their continuous history back to the publication in 1662, once again the year of the foundation of the Royal Society, of John Graunt's *Observations upon the Bills of Mortality*. Among the earliest fellows of the Society there was an active group who were interested in this new study, which was then called 'political arithmetic'. There are many textbooks of the history of statistics in which the new study is connected with the immediately preceding advances in mathematical knowledge, and with the scientific interests of that generation; but it is quite wrong to think that it arose from the sudden application of mathematics to the investigation of society. Statistics did not start from nothing; it built higher a long-standing structure. To understand its relation to the scientific movement as a whole, we must make a rapid survey of the use of quantitative methods in social matters over a long preceding period.

We cannot assign to this, any more than to any

other great historical phase of thought, a definite beginning. Far back in the Middle Ages tables of figures were constructed for certain specific purposes of government. The Anglo-Saxon systems of government were based on enumerations of families: several of these are preserved in Bede's *Ecclesiastical History*.[1] The 'Tribal Hidage', a tabular statement of the number of 'hides' in England, by districts and with totals for larger areas, probably goes back in its original form to the seventh century.[2] For military and financial purposes statesmen necessarily thought in terms of figures; but in the Middle Ages such special concerns were few, and numerical calculation was not extended beyond them or used as an instrument of thought except in very narrow departments. Domesday Book, that wonderfully minute and complete review of the resources of a kingdom, does not contain estimates of their totals, and modern antiquarians have had to make their Domesday statistics for themselves. For William the Conqueror the totals would have had no practical value. What he wanted was to know his precise rights in each place. Whenever any payment fell due he wanted to exact the full amount, and the information he collected enabled him to do this at the time and place where, but for this knowledge, he might have been cheated. He did

[1] Bk. II, c. ix; III, cc. iv, xxiv; IV, cc. iii, xiii, xvi, xix, xxiii; V, c. xix.

[2] See J. Brownbill in *English Historical Review*, xxvii. 625, xl. 497: the latter article has a facsimile of the 'English' text.

not attempt or need to see what the whole amounted to, because the money he received did not form a whole, a single fund. Each payment, as it came in, was earmarked for a specific purpose. The money was only a small part of his dues: his army was provided by tenants owing military service, and many of his other needs by tenants who owed service in the administration, or by payments of food and other goods in kind. There was no public revenue in the modern sense, to be added up in a single total and allocated to the different needs of government.

In the later Middle Ages there are signs that people connected with government were beginning to use collections of figures as the framework of their thoughts about policy. Common medieval thought, as exemplified for instance in the chronicles, handled figures as carelessly as Herodotus; but there is a type of naïve curiosity which likes to collect figures, and in the fifteenth century, if not earlier, this was coming into alliance with political knowledge. There was, for instance, an Englishman, apparently concerned with administration in East Anglia, who jotted down, as he came across them, figures of the length and breadth of England, the length of the coast-line, the number of parish churches, of villages, of counties, of bishops, the number of dioceses in the world.[1] He cannot very well have had any practical use for them, but his curiosity about figures was already leading to

[1] Bodleian MS. Tanner 70, fos. 37 v, 64, dating from *c.* 1484–1500.

comparisons, and this obscure Englishman was only one step away from the point of view of one of his most famous contemporaries, the central figure of the political thought of the Italian Renaissance. Machiavelli used a figure whenever he could. His figures are few, and they are not all good,[1] but he had a grasp of the value of figures in shaping policy. They are one of the elements in his comparisons of the resources of different states, data in those calculations of strength which are characteristic of the modern tendency in his age.

This modern tendency affected the attitude of princes to the government of their states. If Domesday Book is compared with the surveys of their resources made by princes in the sixteenth century, it will be seen that the social foundations of the state had changed so that a public revenue was now the main contribution of a country to the upkeep of government, and this revenue had to be estimated, not perhaps as a single whole, but in a few large branches, and not merely in each year but with rough forecasts for the future. Armies were now hired for pay; civil servants were salaried officials; military stores, far more expensive than before, had to be bought from contractors, and so on through most of the activities of the state. In a more compli-

[1] At the end of the *Ritratti delle cose della Francia* he gives the number of parishes in England as 52,000; the Tanner MS. has 52,080. The real number is about 9,000. The exaggerated estimate was current in the fourteenth century: see Stubbs, *Constitutional History*, 4th ed. (1906), ii. 442–3.

cated economic system the ascertainment of a prince's rights had to be done with a more advanced method, the more so because opposition was becoming more ingenious and itself rested sometimes on special legal or economic knowledge.

As an illustration of this stage of development we may take the statistical work of a German ruler, the Landgrave William IV of Hesse-Cassel, who ruled from 1567 to 1592.[1] Like some of his contemporaries he made a thorough survey of his revenues, and he had two special reasons for doing it; he had inherited a territory diminished in area and therefore needing reorganization, and in contests with his feudatories and with popular rights he wanted to equip himself with the unbreakable weapon of exact figures. The result is embodied in a composite volume known since the eighteenth century as the *Economic State*. At first sight it appears almost miscellaneous. It begins with a very detailed list of fiefs, giving even fuller particulars than Domesday Book, of the agrarian arrangements, mills, fisheries, taxes, and saltworks. It continues with estimates for the expenses of the court and administration, tables of dietary and purchase-prices for the court, of the equivalent values of coins, of wages, and finally a survey of military arrangements, including estimates of expenses based on two actual campaigns in the past. Some things are embedded in it which do not concern us now, but

[1] See Dr. Ludwig Zimmermann's excellent edition, *Der ökonomische Staat Landgraf Wilhelms IV*, 2 vols. (1933–4).

with these exceptions it is all taken up with counting and measuring. The technique is much more developed than that of Domesday Book. There is a table for the conversion of measures of capacity and weight. The estimates of the values of properties are based on averages for three, six, or nine years.

This last point shows that simple mathematical calculations were being used in public affairs.[1] In this instance it is significant that William IV was not only a good administrator with able ministers to help him, but also one of those Renaissance princes who made use of science in their work. He was an astronomer of repute and he showed interest in various branches of science and mathematics. His revised book of fiefs was accompanied by a set of estate-maps which are notable in the history of cartography. About the same time English land-owners were ordering those beautiful and accurate maps of which hundreds still survive in their muniment-rooms. The advance in map-making in the late sixteenth century resulted very clearly from a convergence of economic needs and intellectual progress. There had been great changes in the ownership of land, in its use, and in tenures: there was a need for the defining of rights. At the same time the art of surveying was improved: there were better instruments and better books on

[1] I do not know whether the use of averages in calculations of the annual value of estates was practised earlier in Europe or in Asia. It was the basis of the land-revenue system of Mogul India at the beginning of the seventeenth century: see W. H. Moreland, *India at the Death of Akbar* (1920).

their use. This new cartography was used in the service of the state, for instance by the great Cecil in Elizabethan England, who employed more than one map-maker.[1] In all its aspects it was closely allied to statistics. The estate-maps often had in the corners tables of the amounts of land held by different owners, or the numbers of beasts they had a right to pasture. The county-maps of Saxton, the most notable of Cecil's cartographers, were accompanied by descriptions which gave figures. This was no accident but arose from the nature of the two methods. A map is an abstract statement based on measurement; statistics are abstract statements based on measurement, counting, and calculation. If this appears to be a far-fetched identification, let it be remembered that two of the pioneers of statistical science, Petty and Gregory King, were surveyors before they were statisticians. Neither of them, at any point of his work, got very far away from the geographical point of view.[2]

Thus we find from the early days of the Renaissance the two always intermingling currents of science and *Wirtschaft*, private and political, bringing with them

[1] See Nowell's letter to him in R. Flower, *Laurence Nowell* (1936), p. 16. Sir Thomas Wilson, another protégé of Cecil and of his son, makes considerable use of figures in his State of England of 1600 printed in *Camden Miscellany*, xvi (1936).

[2] Cf. Y. M. Goblet, 'Un précurseur anglais de la géographie humaine . . . Sir William Petty' in *Mélanges de géographie offerts à Vádar Švambera* (1936). This argument, however, should not be pushed too hard. Petty had also been an anatomist, and his *Political Anatomy of Ireland* is not different in method from his other books.

a more extended use of figures. In England statesmen made an increasing use of commercial information which we can hardly refuse to call statistical. Statistical information is collected because it is believed that quantitative knowledge will be useful in shaping policy: the sort of knowledge desired will depend on the prevailing economic conceptions. Once it has been obtained, this knowledge becomes one of the component factors of ideas and policy, so that statistics are historically always both a product and a determinant of thought and action. From the early seventeenth century the figures desired by politicians were those which would throw light on the balance of trade, for economic thought regarded that balance as the key to commercial policy. We possess several documents from the reign of James I in which experts in customs matters made calculations of English imports and exports.[1] Some of them are accompanied by polemical notes maintaining that certain ways of making these calculations are right, and other ways fallacious. In comparison with modern trade figures all these calculations are, to be sure, extremely rough. Even supposing that the customs returns on which they were based were fairly accurate, the margin of error was far too large for any but the most elementary conclusions to be drawn. In spite of this such

[1] Brit. Mus. MS. Lansdowne 152, fos. 175 ff. (calculations of Sir Lionel Cranfield for London, 1605–11, and of John Wostenholme for England, 1612–14); *Acts of the Privy Council, 1615–16*, p. 479.

figures continued to be prepared all through the seventeenth century, not only in England, but in those other countries which had a customs system capable of providing suitable materials.

This point had already been reached when Bacon gathered together many prevailing ideas in his project for a conscious advance of universal science. With him indeed it was no more than a project, and some of his followers only added a formal rigidity to the project without advancing it in substance. This seems to me to be true of the best-known representatives of the 'pansophic' tendency, such as Comenius, whose *Triertium Catholicum* is an over-elaborate scheme for correlating all branches of knowledge.[1] If, however, the attempt to work out a comprehensive system of all the sciences proved to be barren, it was closely related to two other attempts which yielded abundant fruits.

Of these the first was the encyclopaedic tendency. We may indeed talk about an encyclopaedic tendency in various senses. It may be understood as meaning simply universal curiosity, and in this sense it flourished exuberantly in the early seventeenth century;[2]

[1] It was published in 1681, eleven years after the author's death; I have used the facsimile edition, with an epilogue by J. V. Kléma, which was published at Prague in 1920. For the pansophic tendency in general see E. Spektorsky, Проблема Соціальной Физики въ XVII Столѣтiи, i (1910), pp. 328 ff. It is said that a second volume of this useful book was published in 1917, but I have been unable to hear of any copy of it.

[2] See, for instance, the admirable and entertaining chapter in

but it is more commonly taken to mean something more systematic. Curiosity, indeed, can hardly ever be utterly indiscriminate; the merest collector of information usually collects information of some particular kind. Compilers and collectors of information were very active, among them collectors of political and social information. The politics of the time, especially its international politics, created a new demand for political information. Machiavelli's studies of foreign countries were followed by a growing mass of diplomatic *relazioni*, spreading, as the scope of alliances widened, over all Europe, Asia, and America. The wars and religious movements brought the newsletter and the newspaper, and along with them there came into existence books which gave the background of the news for the statesman and the general reader, as the diplomatic reports had given it for the statesman alone. Some were superficial and, for the distant countries, even fabulous; but by the middle of the century it was possible to buy a tolerably good Latin account of the constitution of every important European country, and of the social economy of some of them.[1] Material of this kind was used by teachers in some of the continental universities, and it is of it that the adjective *statisticum* was first used.[2] Attempts were made, in

which the Abbé Bremond showed its place in humanistic devotionalism: *Histoire littéraire du sentiment religieux en France*, i (1916), 255 ff.

[1] For references see *The Seventeenth Century*, p. 215.

[2] For instance in the title of the *Microscopium Statisticum, quo*

a uniform series of books, and even in single folio volumes, to give this sort of survey of the whole world.

The collection and arrangement of data led, as it often has done in the history of thought, to systematic interpretation, and it did so in this instance because the spirit of the scientific movement penetrated to social studies. Descartes himself, who brought the scientific movement to maturity in his mathematical, determinist, materialist physics, did not include man and social relations in his own scope; but it was easy for others to bring them in. His contemporary Hobbes constructed a system of determinist and materialist ethics and politics. In the middle and the second half of the seventeenth century there were many discussions as to how far the Cartesian method could be extended to man. The greatest of all philosophical problems were involved in these discussions, and it is no part of our present task to trace how they ultimately led to the separation of science from philosophy and theology which we have noticed as impending in the time of Newton. What we now have to observe is that at one stage of the discussions there definitely emerged a determinist and materialist tendency in historical thought.[1] We find it fully developed in the works of Sir William Temple. As a

*Status Imperii Romani Germanici representatur*, by Helenus Politianus. I have not been able to find a copy of this work in England.

[1] Isolated instances of this tendency were, of course, known long before, such as the doctrine of the influence of climate on institutions, which was derived from Aristotle and other Greek writers.

young man he was, at least nominally, the pupil of Ralph Cudworth, one of the Cambridge Platonists, and the Cambridge Platonists were in the thick of the controversies about the metaphysics of Descartes. Temple conversed with many of the leading men in Holland, especially his friend John de Witt, whom we shall mention again, and it was in Holland that Cartesianism was first taught in universities. It would be over-sceptical to doubt that these influences helped him to the view that 'most national customs are the effect of some unseen, or unobserved, natural causes or necessities'. He studied politics and economics with the starting-point of science, that the same cause will produce the same effect.[1]

Another stream which may be traced from the 'pansophism' of Bacon's time was 'pantometry', the belief that all things can be measured. The old desire for a scheme of all knowledge was bound to take this form when, with Descartes, the scientific movement came under the domination of mathematics. Descartes himself, in his philosophy, sought for certainties like those of mathematics. There were soon others who tried to reach certainty by the same method in other spheres, even the most unlikely. Spinoza's *Ethics* were *ordine geometrico demonstrata*; we have already seen how Newton's friend Craig tried to make a mathematical theology. These two attempts came some years after the beginnings of political arithmetic, but they will suffice to show that

[1] *Observations upon the United Provinces* (1673), Introduction.

political arithmetic was not an isolated innovation but part of a wide intellectual movement.

In considering its antecedents we must look not only at the intellectual movement but also at its effects in everyday thought and practice. While, at the summit of the intellectual world, the leaders of thought were engaged with mathematics and the quantitative study of nature, the use of figures was becoming commoner and more skilful on the lower levels. Universities and schools spread the knowledge of elementary mathematics through the workaday world. In the commercial countries more and more 'writing schools' taught the practice of book-keeping by double entry. More and more people learnt to carry out measurements and simple calculations. The history of such knowledge among ordinary men is naturally hard to trace; but it seems clear that in this respect the second half of the seventeenth century showed a marked advance from the first half, at least in England. The school books were better and they indicate that a higher standard was required. It will be enough to mention one instance of this. In the first half of the century two systems of calculation were in use in private business. There was the method of written or mental arithmetic which we use now, and there was the more primitive system of manual arithmetic, reckoning by moving counters on a counting-board. This latter now does not survive in England at all except that something like it is used as a means of teaching children to count with the abacus.

We know with reasonable certainty that it ceased to be used by adults in the second half of that century.[1]

By all these processes the way was prepared for political arithmetic. The event usually taken as marking its beginning was indeed the emergence of a new kind of statistical inquiry, more ambitious and more exact than anything that had been attempted before. Graunt's book was called *Natural and Political Observations . . . upon the Bills of Mortality . . . with Reference to the Government, Religion, Trade, Growth, Ayre, Diseases, and the several Changes of the said City* of London. The Bills of Mortality were returns of the deaths which occurred in London. They were prepared by the Parish Clerk's Company, one of the city livery companies, and the first published specimen goes back to 1592. From 1603 they were published uninterruptedly once a week, and the number of parishes included in them was from time to time increased. The only plausible reason that can be assigned for their publication is that they were meant to give warning, or to allay false apprehensions, of outbreaks of the plague, and this is confirmed by a number of circumstances, such as the dates 1592 and 1603, which were both plague years. Sprat, the historian of the Royal Society, was, however, justified in writing that before Graunt's time these papers 'went

[1] Barnard, *Casting-Counter and Counting-Board* (1917), pp. 87–8. It may be worth considering whether the intensified economic competition of the period of Louis XIV encouraged the increased use of mathematics, as it did other kinds of rationalization; but it would be difficult to find direct evidence on this question.

about so many years, through every Tradesman's hands, without any manner of profit, except only to the Clerks that collected them'.[1] We may notice that their end was worse than their beginning. In the nineteenth century a number of parishes ceased to make returns to the Company and the Company, having no means of compulsion, continued to make increasingly defective returns. From 1840 the registrar general's office published complete weekly bills; but the old series, though now utterly valueless, continued to appear year after year.[2] The energy devoted to publishing economic information is not always well directed. So little is known about Graunt's life that it is impossible to say either how he got his mathematical training or how he came to study vital statistics. His election as an original member of the Royal Society, and the publication of a third edition of his book in 1665 for the use of its members, prove that it at once found an appreciative audience among the scientists.

There has indeed been a controversy as to whether Graunt deserves the credit for this work or whether it should go to the extraordinary man with whom he was closely associated, Sir William Petty. That such a doubt should be possible is an added proof, as we saw in the case of disputed technological inventions,

[1] *History of the Royal Society* (1667) p. 243.

[2] J. S. Wharton, *Law Lexicon*, 3rd ed. (1864), p. 121. For the bibliography of the Bills see N. G. Brett-James, *The Growth of Stuart London* (1935), pp. 534 ff.

that the innovation was *partus temporis*; but the grounds for questioning Graunt's claim are not sufficient.[1] Graunt was a cautious, critical worker who, so far as he could, tested the value of his figures and limited his inferences to what appeared reasonably probable. Petty was a man of tumultuous versatility, who flung out a hundred suggestions for one that he considered in detail. He had been in touch with many currents of thought. Educated partly by the Jesuits at Caen, and partly in the medical schools of Leyden and Oxford, he had been amanuensis to Thomas Hobbes, the great English materialist and determinist philosopher. He was full of the idea that numbers could elucidate all sorts of practical affairs, and he gave the new science the name that it kept throughout the eighteenth century: 'political arithmetic'. In what he wrote, about population, trade, revenue, and defence, he used any figures that came to hand, however defective, and his conclusions were for the most part worthless. He convinced his contemporaries of the value of a study which he had not the patience to pursue.[2]

One particular piece of work in which Graunt

[1] For the present state of the discussion it is sufficient to refer to two convincing, though unnecessarily emotional, articles by Professor M. Greenwood in the *Journal of the Royal Statistical Society*, xci. 79 and xcvi. 76.

[2] In addition to *The Economic Writings of Sir William Petty*, ed. C. H. Hull, 2 vols. (1899), which also contains Graunt's pamphlet, the *Life* by Lord Fitzmaurice (1895) and two publications edited by the late Lord Lansdowne, *The Petty Papers*, 2 vols. (1927), and *The Petty-Southwell Correspondence* (1928) should be used.

showed his more scientific attitude was an attempt to construct from the London figures a 'life-table', a table exhibiting the number of persons who survived at certain ages. Such tables are nowadays in constant use in the offices of insurance companies and are printed in such books of reference as *Whitaker's Almanack*. Then they were a new invention, and life-insurance was not yet a practical possibility, because its basis in calculation and known fact had not been laid. What method Graunt used is not quite clear, and as a mathematical exercise his attempt is inferior to those already made by the two great thinkers Pascal and Huygens about the calculation of chances in games of hazard, to which the same principles apply. Down to this time vital statistics were the concern only of private inquirers, and they had not reached the stage of practical application. In 1671 another step forward was taken. The great Dutch statesman John de Witt had to find money for a war against Louis XIV. He had been trained in mathematics and had written a book on geometry. With the advice of another mathematician he now prepared a life-table as the basis of an offer of state-annuities. He had to rely on conjecture for the figures of the expectation of life; but he followed the method of Huygens, and his confidence in that method heralds a new era in finance.[1] The first really sound table was that by Halley, derived from the figures of mortality in

[1] For references to expert discussions of this work see N. Japikse, *Johan de Witt*, 2nd ed. (1928), p. 312, n. 1.

Breslau, and printed in the *Philosophical Transactions*.[1] The primary interest of such calculations was still that of state-finance; the government of William III raised various war-loans for which it paid in the form of life-annuities; but within a few years the history of the true life-insurance began, with its far-reaching social consequences, and its great incidental reinforcement of the belief in statistical method.[2]

Statistics as we know them in modern life are very different from these crude anticipations. They are manipulated by means of a highly specialized technique, designed to test the data thoroughly and to extract from them everything that they can be legitimately made to prove. This technique would not have grown up if it had not been for the development of the external machinery by which the data are provided: its foundation is the mathematical theory of probabilities, but this theory is applied only to large numbers, and in the social and economic sphere the large numbers appropriate for it have been for the most part collected, and in the eighteenth century could only be collected, by the state. The beginning of the modern period may be put at 1801 when both England and France for the first time took a census of population, for the census-figures are the measuring-scale of all our other immense statistical accumulations. Yet, although the connexion is indirect, some

[1] Vol. xvii (1694) for 1693.

[2] For its beginning see W. R. Scott, *History of Joint-Stock Companies to 1720*, iii (1911), 366 ff.

light is thrown on the transition from the early to the modern statistics by the history of commercial statistics from the time of Petty. These were collected not by private inquiries but by the state. During the period of Colbert ministers, both in France and England, sometimes tried to get better and fuller trade figures. In France there was a serious obstacle in the way: even after the reforms of Colbert the tariff-system was so complicated that the government could not construct satisfactory national figures. England, however, was a single unit for customs purposes. In 1671 the government took over almost all the customs administration from the farmers and soon afterwards the increasing demand for more accurate figures at last brought about a striking advance. What decided it was the financial crisis of 1695–6. This was one of the worst moments of the wars against Louis XIV: there had been heavy losses of shipping, the currency was in a bad way, and a recoinage had to be undertaken. Parliament inquired with alarming pertinacity into the causes of the miscarriages, and one of the permanent results of these inquiries was the creation of the office of the inspector-general of imports and exports, the first special statistical department successfully created by any western European state.

The inspector-general was an official of the customs, and he reported regularly to parliament, the treasury, and the newly created board of trade. He and his clerks drew up, from materials supplied by

the customs officers, full and minute annual accounts by quantities and estimated money-values, of all English imports and exports. From time to time they extracted, as they were called for, returns of special commodities or of trade with particular countries. Their methods, though in some ways open to criticism from the start, were at any rate much more satisfactory than those that had previously been known. We do not know to whose initiative this new step was due. Possibly it was William Lowndes, the secretary of the treasury, to which department the commissioners of custom were subordinate. It seems certain that the new office was not copied from any foreign model. There is nothing to connect it with the names of any of the early statisticians. Petty and Graunt were dead; Halley was employed in 1696 in the re-coinage but seems never to have worked at trade-figures; but Gregory King, the most important economic statistician of his day, appears to have been employed by the treasury at or about this time.[1] It would, however, scarcely be rash to say that the foundation of the new office was partly due to the popularity of political arithmetic. The same crisis which brought it into existence also caused the foundation of the board of trade, and the board of trade, of which Locke was a member, also exemplified the now prevailing belief

[1] This I infer from a number of papers in the important bundle of his unpublished 'Exercises in Political Arithmetic' in the Public Record Office, T 64/302.

in the value of figures. When it turned its attention to the poor law, it obtained, through the archbishops, returns from the clergy of the amounts paid in each of their parishes in poor-relief.[1] The number of replies received was only 4,415, less than half that of the parishes in England; but the attempt, for which there was no precedent, was a symptom of the new intellectual attitude to social questions.

There is another instance, close to these in time, of the exact quantitative study of economic facts. These were facts of the past, including the remote medieval past; but the impulse to study them probably came partly from the currency problems of the reign of William III. The facts themselves, with much in the way of interpretation, were given in 1706 in a book called *Chronicon Preciosum* by William Fleetwood, afterwards bishop of Ely. It was the first noteworthy European book on the history of prices, and it remained for many years the best book on that new subject. Like the books on political arithmetic it had roots in various earlier lines of inquiry, but in a general way it belongs, like them, to the movement towards quantitative social science.[2]

At the beginning of the eighteenth century this social science seemed to have an established position and a great future. The hopes of that time are well

[1] The papers relating to this matter are among the records of the old board of trade in the Public Record Office.

[2] For a fuller discussion of this book see the Appendix to the present essay.

stated by Arbuthnot in his *Essay on the Usefulness of Mathematical Learning*. For the most part that essay follows familiar lines; but it contains one claim which Arbuthnot's predecessors had not made.

'Arithmetic is not only the great instrument of private commerce, but by it are (or ought to be) kept the public accounts of a nation; I mean those that regard the whole state of a commonwealth, as to the number, fructification of its people, increase of stock, improvement of lands and manufactures, balance of trade, public revenues, coinage, military power by sea and land etc. Those that would judge or reason truly about the state of any nation must go that way to work, subjecting all the forementioned particulars to calculation. This is the true political knowledge. In this respect the affairs of a commonwealth differ from those of a private family, only in the greatness and multitude of particulars that make up the accounts. Machiavel goes this way to work in his account of different estates. What Sir William Petty and several other of our countrymen have wrote in political arithmetic, does abundantly show the pleasure and usefulness of such speculations. It is true, for want of good information, their calculations sometimes proceed upon erroneous suppositions; but that is not the fault of the art. But what is it the government could not perform in this way, who have the command of all the public records?'[1]

This passage shows much wisdom. It is perhaps a little over-coloured, for instance in the reference to Machiavelli; but in the main it represents the attitude

[1] *Life and Works*, ed. Aitken (1892), pp. 421–2.

of judicious men at that time. Leibniz, who had perhaps a wider outlook on the state of thought than any other man of his generation, wrote his view about another aspect of 'pantometry' a couple of years later. He said that various authors had promised mathematical demonstrations in metaphysics and ethics but few had succeeded in them, because of the great trouble involved in carrying them out with rigour. They never could appeal to a wide audience; but investigators who undertook them in the proper way were not likely to repent it.[1] These hopes were not fulfilled. During the greater part of the eighteenth century the attempt to apply quantitative thought to human affairs made no substantial progress. It was allowed a place, if a modest place, in the general work of science, but the idea of an all-inclusive, mathematical study of the universe receded.

This may be illustrated from the form then taken by the encyclopaedic tendency. In the early eighteenth century the standard encyclopaedias began to take the form, familiar to us, of a number of separate articles arranged in alphabetical order. We expect, indeed, to find in an encyclopaedia articles on philosophy and on the sciences which shall show how they are related to one another; but the advantage of the arrangement is, not only that it is convenient for ready reference, but also that, when each branch of knowledge is growing in its own way and without

[1] *Nouveaux essais* (1765), II, c. xxix, 12. This posthumously published book was written in 1703.

regard to its supposed place in an ideal whole, it can be summarized by itself as a separate unit. Alphabetical order, as the plan not merely of the index but of the whole work, means that, while the attempt at comprehensiveness is still made, the systematic correlation is relegated to a subordinate place. We may expect it to arise when knowledge is growing in many directions, and not in the framework of an accepted interpretation of the whole. It was in such a condition of economic knowledge that Savary des Brulons planned his *Dictionnaire universel de commerce, d'histoire naturelle, d'arts et métiers*, posthumously published in 1723 and afterwards adapted into English by Malachi Postlethwayt. The conditions were similar in a wider sphere at that time, when the Newtonian system was elbowing the old metaphysics aside, and when the positive sciences were following divergent paths of observation and experiment. John Harris, a fellow of the Royal Society, published in 1704 the first edition of his *Lexicon Technicum*, an alphabetical dictionary of mathematics, science, and technology. Ephraim Chambers, also a fellow, brought out in 1728 the first edition of his still more comprehensive *Cyclopaedia*, from which all our many modern encyclopaedias are lineally descended.

Chambers's two folio volumes were more comprehensive than those of Harris; they included a good deal, for instance, about law and heraldry, which went beyond the boundaries of science; but with one remarkable exception they let the social sciences

alone. Economics had not then reached the status of a science, and there is only one economic article, on 'Political Arithmetic'. That social statistics won a place in this early encyclopaedia was due to its having a mathematical form. But there was nothing in the rest of the encyclopaedia to connect it with any other branch of knowledge. It had no place except its alphabetical place; its ascertained results were summarized in one short article, and there was no sign of its possessing a living principle capable of further great advances.

On the practical and administrative side, as on the side of theory, the start made by statistics in the late seventeenth century was hardly more than a false start. The English administration methodically collected its figures of foreign trade, and they were increasingly used to support the arguments of pamphleteers and politicians. The French and other governments found it convenient to set up similar statistical offices; but the English commercial statisticians discovered no important economic truth which was not otherwise known. At the most they prepared the way for true quantitative thinking. They worked usually in a spirit of unenterprising routine, and the best economic thinkers made little use of their materials, rightly considering that they were not prepared with sufficient critical care. Adam Smith was in line with the best of his predecessors when he dismissed the possibility of making accurate estimates of trade with the plain statement: 'I have no great faith in political

arithmetic.'[1] By his time the high hopes of Petty and Arbuthnot were dead, and quantitative methods in economics and in social thinking generally had to make a fresh start in the late eighteenth century.

How are we to account for this interruption in a movement which had seemed so powerful a century before? A full answer would, no doubt, have to draw upon many factors of eighteenth-century history, some of which have not been sufficiently explored for a full answer to be possible as yet. Three things may, however, be said which would form parts of the answer. First, the slack period of social thought came at much the same time as a slack period of scientific thought: the central eighteenth century was not, like the seventeenth, a time of cardinal scientific discoveries. Secondly, on the side of practice, the inactivity in exploring social facts was part of the general administrative torpor of England in the eighteenth century. In France, where social administration was vigorous and intelligent, quantitative study appears to have made more progress both in method and in achievement. The third point is the most important, for it concerns the potentialities of the quantitative method itself. The attempt was made to apply it separately, not as one element in an all-round examination of human and social life by all the methods which can explain them. Quantitative study did not begin as part of a comprehensive social science, embodying the knowledge which ethics,

[1] *Wealth of Nations*, ed. Cannan, ii. 36; see also i. 439.

political thought, and theology had already attained. It was not continuous with the main tradition of thought on human problems; it even deliberately broke away. It did so at a time, the late seventeenth century, when the old unities of thought and action were everywhere falling apart; when science and philosophy, philosophy and religion, religion and government were drifting away from their old, sometimes quarrelsome, intimacies into estrangements, mutual indifference, profound hostility. It began in isolation precisely at the time when isolation was certain to make it sterile. Its disappointments were typical of an age in which western civilization was breaking up into parts that no longer made a whole.

*Additional Notes.* On p. 137, ll. 17–19, the words from 'its foundation' to 'large numbers, and' should be deleted.

Some of the statements on p. 139 are now known to be incorrect, since Mr. R. M. Lees, in an article in the *English Historical Review*, liv (1939), 38 ff., has shown that the initiative which led to the statistical work of the board of trade came from the economist Charles Davenant.

The first sentence of the second paragraph on p. 149 may be supplemented as follows. From 1714, when Fleetwood became Bishop of Ely, he was concerned with the disputes between Bentley and Trinity, in some of which, such as that of Serjeant Miller's fellowship, the same question arose. Monk in his *Life of Richard Bentley*, 2nd ed. (1833), ii. 393 n. ascribes to Fleetwood the opposite view to that expressed in his book.

## APPENDIX

## THE OCCASION OF FLEETWOOD'S *CHRONICON PRECIOSUM*

THERE is a little antiquarian puzzle about the reason why William Fleetwood published his book on the history of prices when he did; the question is in itself of no importance, and the solution is easy, but the evidence suggests some considerations of wider interest. The title-page of the book, which first appeared anonymously, gives a good description of the contents. Printed continuously, and without some of the capital letters, it runs thus:

> Chronicon Preciosum: or, an account of English gold and silver money; the price of corn and other commodities; and of stipends, salaries, wages, jointures, portions, day labour, etc., in England, for six hundred years—showing from the decrease of the value of money, and from the increase of the value of corn and other commodities that a Fellow, who has an estate in land of inheritance or a perpetual pension of five pounds per annum, may conscientiously keep his Fellowship, and ought not to be compelled to leave the same, though the statutes of his College (founded between the years 1440 and 1460) did then vacate his Fellowship on such condition.

The college has been identified as King's College, Cambridge, of which Fleetwood was himself a fellow: it was founded by King Henry VI in 1441.

King Henry was also co-founder of an Oxford College: but as All Souls was founded in 1437, not between 1440 and 1460, it might seem to have nothing to do with this case of conscience. A doubt, however, arises when we observe that the title just quoted is that of the second

edition (1745),[1] and that the first is quite different, reading simply 'Chronicon Preciosum or an account of English money, the price of corn and other commodities for the last six hundred years. In a letter to a student in the University of Oxford'. This is explained by an entry of 16 November 1706 in the diary of Thomas Hearne:

There is come out . . . a book call'd *Chronicon Pretiosum* . . . the design of which is to keep Mr. Worth in his fellowship of All-Souls, which in justice and according to the letter of the statutes he ought to leave on account of the archdeaconry of Worcester conferred on him which is rated more in the Queen's Books than is consistent with his oath, though to avoid this the author (whoever he be, some say Dr. Fleetwood) has endeavoured to shew (but as far as I can yet perceive very knavishly and weakly) that he ought to keep both because his archdeaconry is not so much as required by the statute, provided the value of money be conferred as 'twas at that time when the statutes were made. . . . The author in the preface shews himself ignorant of our coyns in several respects, and not to know that formerly payments were made in kind not specie.[2]

But then Fleetwood and Worth were Whigs, which Hearne decidedly was not.

Hearne's story is confirmed by a volume of papers in

[1] There is no evidence to show how the title came to be altered in this posthumous edition; but I conjecture that the book was reprinted not from the first edition (dated 1707) but from the reprint in the folio volume of Fleetwood's *Works* published in 1737. Here the title was abbreviated to *Chronicon Preciosum, or An Account of English Money, Corn, &c.* The remaining words may well have been added in good faith to fill up the new title-page.

[2] I have corrected the text given in *Remarks and Collections of Thomas Hearne*, i (1885), 307. There is a further reference to the incident on p. 316.

the muniments of All Souls. Before they were bound the papers bore the inscription in Warden Gardiner's hand 'Concerning the Unnecessary Trouble given to myself and the College by Mr. Worth'.[1] There is no need to recount how Worth appealed to the archbishop of Canterbury as visitor, but finally withdrew his appeal and lost his fellowship.[2] It must be admitted that the papers contain no reference to Fleetwood's book, but the interesting point which emerges from them would be reinforced instead of being weakened if it could yet be proved that the book was not published to help Worth. The point is that this was not an isolated incident, but that the principle involved in it was at that time exercising the minds of a number of people. Among these papers is a letter from the warden to Sir Nathaniel Lloyd, a jurist and a member of the college, which mentions an earlier occurrence of the same kind. In 1702, shortly after pronouncing sentence in a case similar to that of Worth, the bishop of Winchester, as visitor of New College, had at the request of the warden and fellows fixed the income which under their statutes should be incompatible with a fellowship at the new and higher amount of £80.[3]

Here then were New College and All Souls both thinking about this question, and we may add King's after all, for, although Fleetwood published his book as a *pièce d'occasion*, he must have spent time in collecting the materials for it. The book was published less than a year after the collation of Worth to the archdeaconry: it is therefore very unlikely that it was this incident which

[1] C. Trice Martin, *Catalogue of the Archives of All Souls College*, pp. 340–1.

[2] See *Dictionary of National Biography*, s.n. 'Worth, William'.

[3] No. 189 in the volume of papers.

suggested to Fleetwood that questions of this sort were monetary questions. It is often assumed that this interest in the change in the value of money since the Middle Ages was new at this time. One precursor of Fleetwood has, indeed, been recognized, Rice Vaughan, whose posthumous *Discourse of Coin and Coinage*, published in 1675, attempted a comparison of the value of money in 1352 and about 1630, and tried to prove that it had 'grown principally, and in a manner solely, out of the great quantities of gold and silver come into the Kingdom of *Spain* out of the *West* and *East Indies*, within this Hundred years or thereabouts'.[1] It does not appear from Vaughan's text why he took up this question. He dealt with almost every aspect of money and had a considerable knowledge of earlier English and French writers. There need not indeed be any specific reason: the contrast between current and earlier prices was striking enough to attract the attention of antiquarian writers who were not profound thinkers on social and economic questions. Thomas Fuller, for instance, in his *Worthies* of 1662 several times noticed that this or that commodity had become much cheaper or much dearer, in much the same way as medieval or Elizabethan chroniclers noted years of special cheapness or dearness. It was, however, a real problem which was raised by the late François Simiand when, after considering the books of Vaughan and Fleetwood, he asked, with his usual acuteness, why it was that, although the price-revolution went through its most decisive phase in the sixteenth century, it was not until so much later, not

[1] In cap. xi, pp. 56 ff., in the reprint in *Select Collection of Scarce and Valuable Tracts on Money*, ed. J. R. McCulloch (1856). The date of composition was *c.* 1630–5.

in fact until it had ended, that it was studied in terms of exact figures.

Il est véritablement surprenant que ces si nombreux intéressés, surtout ceux qui étaient lésés . . . ne se soient pas préoccupés plus tôt de rechercher dans les faits s'il ne s'était pas produit un changement dans ces équivalences monétaires et souciés de le constater ou faire constater et d'en tirer argument.[1]

He suggested that the social changes which resulted from the fall in the value of money, the reversals of fortune for individuals and classes, may themselves have prevented serious investigation. That may well be so, but something may be added to this very general answer.

In the first place it is not altogether true that the question was ignored before the time of Vaughan. There is a continuous series of discussions of it in England from the late sixteenth century. The spectacle of the price-revolution and the loss it caused to those who granted long leases of their lands at fixed rents led to the well-known statute of 1575–6, 18 Elizabeth, c. 6, by which a third part of the rent upon leases made by colleges should be reserved in corn.[2] This statute had the incidental result of providing historians of prices with some of their best materials in the records of corn prices of Eton, Winches-

[1] *Recherches anciennes et nouvelles sur le mouvement général des prix* (1932), p. 289.

[2] For the antecedents and working of this act see H. F. Howard, *The Finances of St. John's College, Cambridge* (1935), pp. 33–4. O. van Rees, *Geschiedenis der staathuishoudkunde in Nederland*, i (1865), 340–1, refers to a *plakkaat* of 5 March 1571 for changing money-leases into leases in *vruchten* and to Graswinckel's unfavourable view of it. For the effects of the price-revolution on long leases see Sir Thomas Wilson, 'State of England in 1600' in *Camden Miscellany*, xvi (1936), 39.

ter, Oxford, and Cambridge. It protected the colleges against the full effects of the rise in prices; but in the early seventeenth century, about a generation after it was enacted, a new attack was made on their revenues and those of the parochial clergy. This was the Puritan attack on tithes. Both in the attack and the defence the main arguments were scriptural and legal, but the economic facts did not escape notice. It was recognized that over long periods of time tithes paid in kind provided a more stable remuneration for the clergy than fixed money payments. Sir Henry Spelman, one of the most learned historians among the defenders of tithe, owned the manuscript and was probably the author of a tract on the price-revolution written as early as 1594.[1] In this now incomplete dialogue he gave one to three as the proportion of the change in prices, and mentioned, as one among other causes contributing to it, the influx of silver since 'we have wimbled even into the Bowels of *Plutus's* Treasure (the Indies)'.[2] In his posthumous work on tithes he referred here and there to the great change in the value of money since the Middle Ages.[3] In a shorter piece on the same subject he expressed himself very vaguely about the reasons for this change. After mentioning a number of facts in evidence of it he wrote:

[1] 'Discourse Concerning the Coin of the Kingdom', in *Reliquiae Spelmannianae*, ed. E. Gibson (1698), pp. 203 ff. He deals with monetary standards in the first part of his *Glossary* (1626) under 'Esterlingus' and 'Libra'.

[2] For the earlier history of this explanation see E. J. Hamilton, *American Treasure and the Price Revolution in Spain* (1934), pp. 292 ff.; *Discourse of the Common Weal of this Realm of England*, ed. Elizabeth Lamond (1893), p. xxxiii.

[3] 'Larger Worke of Tithes' in the collection *Tithes Too Hot to be Touched* (1646), pp. 130–1, 153.

'How rates are raised in the present age (whether by scarcity of things, or by the increase of people, or multiplication of coyne, or all) is not unknowne to any, and much too experientally by many whose portion is too penurious for their necessary expenses.'[1] Spelman's collaborator Jeremy Stephens, published these works in the critical year of the tithe controversy, 1646. In his preface he set out the orthodox view of the price-revolution:

If an hundred pounds according to these times, should be allowed for a stipend to a Minister yearly, it maybe as much in value as £300, or £400 in the compasse of an hundred years past; and so likewise of every hundred years since the Conquest, and before it: which hath happened of late times by the discovery of the West-Indies, the trade and commerce thither, and the riches of their mines brought into Europe, all which may fail in the next age, or be otherwise diverted, and stopt, beyond the imagination or providence of any man.[2]

The book in which this last passage occurs has a direct connexion with Fleetwood's work. It is mentioned in the long extract from the Whig clergyman and historian White Kennet, with which, in order to prove the utility of the historical study of prices, Fleetwood concludes.[3] White Kennet recapitulated some of the historical examples which had already been cited in the discussion of tithes, added more of his own, and argued with convincing force 'how fatal' the commuting of tithe for fixed money payments would in time prove to be.

The question of college fellowships was then neither the most important nor the earliest which had directed

[1] *An Answer to a Question of a Gentleman of Quality—Concerning the Settlement or Abolition of Tithes* (1646), p. 6. [2] p. 18.

[3] The original is White Kennet, *Parochial Antiquities* (1695), pp. 604–6.

attention to the history of prices, and in working at that history Fleetwood was continuing the studies of predecessors whose books he knew. He had, however, further reasons for doing so. There were two other tendencies in the economic thought of the period which led to the study of prices. The first, we know, affected Fleetwood directly: he was interested in currency problems. In 1694 he published a *Sermon on Clipping*,[1] and in the *Chronicon* he expressed a view of his own about how the recoinage in William III's time might have been avoided.[2] Now, in the controversy about monetary theory which preceded the recoinage, the price-revolution was discussed: Locke was well aware of its significance.[3]

The second tendency which is relevant here is one which economics then shared with other sciences, the tendency to use quantitative methods. It was the period of the rise of statistics, not only of vital statistics but of commercial statistics and the application of arithmetic to economic problems of all kinds. Fleetwood seems to have been the first writer who effectively impressed on economists the value of collecting the exact facts of prices in the past. After the publication of his book, but not, so far as I am aware, before it, some of the early statisticians worked on price-history. Fleetwood made it one of the regular branches of economic study, and he did so because economic thought had reached a stage where it was needed.

[1] Reprinted in his *Works* (1737), p. 69.

[2] p. 57 in the first edition.

[3] 'Considerations of the Lowering of Interest', in *Works* (1823), v. 46 ff.

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